THE DEVELOPMENT OF A METHOD FOR PREDICTING STATICAL STABILITY OF A VESSEL IN PRELIMINARY DESIGN

EDWARD CARTER THOMPSON, JR.
AND
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THE DEVELOPMENT OF A METHOD FOR PREDICTING

STATICAL STABILITY OF A VESSEL IN PRELIMINARY DESIGN

by

Edward Carter Thompson, Jr., Commander, U. S. Coast Guard
B. S., U. S. Coast Guard Academy, 1948

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B. S., U. S. Coast Guard Academy, 1943

Submitted in Partial Fulfillment

of the Requirements for the

Degree of Naval Engineer

from the

Massachusetts Institute of Technology

1951

Cambridge, Massachusetts
18 May 1951

Professor J. S. Newell
Secretary of the Faculty
Massachusetts Institute of Technology
Cambridge, Massachusetts

Dear Sir:

In accordance with the requirements for the Degree of Naval Engineer, we submit herewith a thesis entitled: "The Development of a Method for Predicting Statical Stability of a Vessel in Preliminary Design."

Respectfully yours,

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NOTATION

L	LENGTH
B	BEAM
D	DEPTH
H	DRAFT
Δ	DISPLACEMENT, TONS
∇	VOLUME OF DISPLACEMENT
C_B	BLOCK COEFFICIENT
C_P	LONGITUDINAL PRISMATIC COEFFICIENT
C_V	VERTICAL PRISMATIC COEFFICIENT
C_W	WATERPLANE COEFFICIENT
C_X	MIDSHIP SECTION COEFFICIENT
G	THE POSITION OF THE CENTER OF GRAVITY OF A VESSEL, ACTUAL OR ASSUMED
K	THE INTERSECTION OF A VESSEL'S CENTERLINE WITH THE BASE LINE
KG	THE DISTANCE BETWEEN K AND G
Z	THE INTERSECTION OF THE LINE OF ACTION OF THE FORCE OF BUOYANCY WITH A PERPENDICULAR TO THAT LINE
GZ	THE DISTANCE FROM G TO Z, THE RIGHTING ARM OF A VESSEL
KZ	THE DISTANCE FROM K TO Z, A RIGHTING ARM BASED SOLELY ON THE GEOMETRY OF A VESSEL WITHOUT REFERENCE TO G.
θ	THE ANGLE OF INCLINATION OF A VESSEL IN DEGREES

I ABSTRACT

Title of Thesis: The Development of a Method for Predicting Statical Stability of a Vessel in Preliminary Design.

Names of Authors: Edward C. Thompson, Jr.
Austin F. Hubbard

Submitted for the degree of Naval Engineer in the Department of Naval Architecture on May 18, 1951.

The authors have developed a procedure for obtaining a workable method giving satisfactory accuracy in preliminary ship design for predicting the curve of statical stability of a vessel when only the principal dimensions and hull coefficients of the vessel are known. The stability data upon which the development is based was obtained by mechanically integrating a parent hull form from Taylor's Standard Series and expanding the resulting righting arm data to cover a range of ship forms. The methods of data expansion used were those suggested in the 1949 Thesis by Church and Robinson entitled "The Estimation of Transverse Statical Stability from Form Coefficients and Principal Dimensions", but modified as considered desirable to improve accuracy and convenience of application.

The principal advance in this thesis beyond previous similar works is the manner in which the present authors have integrated the accumulated stability data into a practicable method for stability prediction. This is briefly as follows: A series of stability parameter diagrams were devised from which values of a dimensionless righting arm coefficient may be selected using as arguments the parameters draft/depth, depth/beam and longitudinal prismatic coefficient. The righting arm is then determined by the following relation:

$$GZ = \left[{}^{KZ}/_{B}\right] \times B - KG \sin \theta$$

where GZ is the righting arm in feet

$^{KZ}/_{B}$ is the dimensionless righting arm coefficient obtained from the diagrams

B is the ship's beam in feet

KG is the vertical distance from the base-line to the estimated position of the ship's center of gravity.

θ is the angle of inclination

By plotting the derived values of righting arm versus the corresponding angles of inclination a predicted curve of statical stability may be drawn.

The effect of sheer is introduced into the method by correcting the actual depth of the vessel amidships by an expression developed by the authors for this purpose.

Curves of statical stability predicted by this method showed satisfactory agreement with conventionally constructed curves for ships within the range of hull forms for which the stability data is considered of suitable accuracy.

The thesis is concluded by recommending certain refinements of procedure which the authors believe will produce a method for predicting statical stability in preliminary design with satisfactory accuracy over any desired range of hull forms.

II INTRODUCTION

In preparing the preliminary design of a ship, the first objective is to establish the displacement, the principal dimensions and the coefficients of form that will most nearly provide the prospective ship with certain prerequisite characteristics. The closer these values can be predicted in the early stages the fewer will be the changes required later, and the efficiency of the whole design procedure will be improved. Methods are available for estimating the power of the propelling machinery, weight of the ship, structural strength, initial stability, carrying capacity and other important items prior to the delineation of the lines. There is, however, little information that will enable the designer to make a satisfactory prediction of the statical stability characteristics at large angles of inclination at this stage of the design procedure. Therefore the ability to make satisfactory predictions with respect to most of the specified characteristics is somewhat nullified by the possibility of changes required at the completion of the traditional stability calculations. To obviate this situation a satisfactory method of predicting statical stability characteristics before making the lines drawing would be invaluable. It is the purpose of this thesis to develop such a method.

The stability of ships has long been considered a very important and somewhat elusive ship characteristic. Numerous methods, analytical and empirical, have been proposed for estimating statical stability. To acquaint the reader with the current status of the quest for preliminary design stability data a resumé of methods applicable to or specifically originated for the solution of the problem is presented.

Among the purely analytical methods were the formulas of Dr. Heinrich Shultz, published in Schiffbau in 1920 for the purpose of determining the ordinates of the stability curve, the maximum righting arm and the range of stability. R. F. Aleman in an M.I.T. Thesis in 1938 titled, "Review of an Analytical Method to Calculate Stability", applied the Shultz formulas to merchant-type vessels. The resulting curves, when compared with the curves computed from the designs showed fair similarity with the vessels floating near their load water lines. Messrs. Guney and Unel in an M.I.T. Thesis in 1944 titled, "Development of an Equation Based on Hull Characteristics for the Angle at which Maximum Righting Arm Occurs" applied the Schultz formulas to naval-type hulls but were unable to arrive at satisfactory results without the use of emperical coefficients applicable to the type of ship in question.

Among the best known of the analytical methods in the United States is the formula of J. C. Niedermair published in the Transactions of the Society of Naval Architects and Marine Engineers in 1932. This formula gives the righting arm as a function of the initial transverse metacenter, the angle of inclination, and the initial metacentric radious. The author claims good accuracy from the formula in constructing the curve of statical stability up to a maximum of 30° heel, or to the angle of the deck edge immersion if it occurs at less than 30° heel, for the "usual merchant ship". This formula may be employed in preliminary design in conjunction with methods of estimating GM and BM as given by Prof. G. C. Manning in The Basic Design of Ships.

N. H. Burgess in a paper entitled "Stability Coefficients", published in the 1943 Transactions of the Institution of Naval Architects proposed a method of estimating the statical stability curve of a vessel in the preliminary design stage. The method for its application requires only the knowledge of the principal dimensions and hull coefficients of the new design plus certain stability data on a vessel having lines similar to the vessel in question. The author prepared the required stability data for twenty-five different vessels to provide a basis for application of the method. The procedure is to determine for various angles of heel the buoyancy lever, BR, of a prism having the same midship section shape and area as the design in question except that the depth of the prism is increased by 1/3 of the mean deck sheer of the corresponding ship. The ratio of BR for an actual ship to the BR of its corresponding prism for a design having similar lines is then selected for the various angles of heel from the tabulated data on the twenty-five ships previously mentioned. The tabulated BR ratios multiplied by the BR's for the design in question at the various angles of heel give a BR for the new design. Then the righting arm, $GZ = BR - BG\sin\theta$. KB and KG must be estimated by any convenient method. It is recognized that the accuracy of the method depends largely on how nearly geometrically similar are the new design and the parent ship. The author gives no indications of the degree of accuracy to expect in the general case.

In 1947, a paper on "Residuary Stability" by C. W. Prohaska, Professor of Naval Architecture at the Technical University of Copenhagen, was published in the Transactions of the Institution

of Naval Architects. Herein the righting arm is considered to be composed of two parts, one part, GM sin θ, depending on metacentric height, and the other, MS, the "residuary stability arm", where MS is the perpendicular distance from the line of action of the force of buoyancy in the inclined position to the initial transverse metacenter. This method is similar to the Niedermair formula and may be used under the same conditions.

In recent years investigators at M.I.T. have pursued the problem of determining statical stability characteristics in the preliminary design stage prior to delineation of the lines by a more direct approach. The procedure has been to select various parent hull forms and while varying each in some systematic manner to integrate for righting arms at several angles of inclination. The data obtained from these hull series has been plotted for use in estimating curves of statical stability for vessels in the preliminary design stage having hull coefficients and geometrical characteristics comparable with the parent forms. The major differences in these methods have been the manner of delineating the parent hull forms and the parameters used in plotting the derived data.

At M.I.T. the method of predicting statical stability characteristics from hull coefficients by using data from stability calculations on systematically varied hull series was commenced by Messrs. Ramsey and Latimer in 1945. Their hull series were of purely geometrical construction, consisting of transverse sections of triangular, elliptical or rectangular underwater portions and vertical sides above the load water line. All hulls had the same profile, which included sheer. A number of hulls were integrated to cover a range of hull coefficients sufficient to test the results on various

types of naval vessels for which the method was primarily intended. In general, the shapes of the derived curves of statical stability compared favorably with those constructed directly from the vessel's lines by the usual procedure. However, the derived values of maximum righting arm varied from several percent to about twenty-five percent less than the values obtained from the actual designs. The authors state that most of the differences could be traced directly to the large amount of flare or the unusually wide stern of the hull under consideration. This sounds like a reasonable explanation, but the manner in which it was deduced is not clear. Further, this thesis emphasizes the fact that the derived data should only be used for ships geometrically similar to the parent series and that whereas the method is not accurate for obtaining absolute values of righting arm it is believed to be good for determining the effect on righting arms of small changes in design dimensions and coefficients.

In 1946 McKay continued the work of Ramsey and Latimer by obtaining cross curves of stability for one of the original hull forms by varying the draft to depth ratio as had been suggested by the previous investigators. McKay believed that within liminations of the original thesis his method of developing cross curves, if extended to cover the range of hull coefficients found in normal ship forms, would provide a means of predicting the stability curve in the preliminary design stage.

Concurrent with McKay's work, Messrs. Kelley, Jones, Crawford and Gooding in an M.I.T. Thesis entitled, "A Method for Predicting Statical Stability" concluded that the development of stability data

from series of geometrically-related hulls was the most promising method of predicting the statical stability characteristics of a vessel in the preliminary design stage, but that the artificiality introduced by employing regular geometric shapes for transverse ship sections resulted in the inaccuracies found in Ramsey and Latimer's method. After rejecting the use of actual ship-shape forms on the grounds that it would be difficult to determine the cause of variations in the curve of statical stability unless only one hull parameter was varied at a time, the use of hulls delineated from Taylor's Mathematical Lines was decided upon. Two such hulls were integrated for stability data holding the longitudinal prismatic coefficient constant while varying the block coefficient. As the data prepared by Messrs. Kelley et al. was not of sufficient scope to be of general use in predicting statical stability curves they suggested that the work be continued in the same manner by succeeding investigators.

In a thesis completed in January, 1948, titled, "A Method of Predicting Statical Stability from Hull Coefficients", Messrs. Randall, Stark and Meyer continued the work of Kelley et al. by delineating six more hull forms from Taylor's Mathematical Lines. In each of the six parent hull forms only the longitudinal prismatic coefficient, the block coefficient, or the waterplane coefficient was varied from the original design. Each of the parent hull forms was then integrated for stability data while systematically varying values of the beam-to-draft ratio and the depth-to-draft ratio. From the results statical stability curves were constructed and compared with the curves for actual vessels. In general, the shapes of the predicted curves were of the same general nature as those of the actual curves,

but the values of maximum righting arm were greater than the actual righting arms, up to approximately 15% error. Messrs. Randall et al. concluded that their method enabled the prediction of an approximate curve of statical stability for any vessel with hull dimensions and coefficients falling within the series. Whether the term "hull dimensions" is intended to mean geometrical similarity is not clear. It would appear that in addition to the requirements of like dimensions and coefficients, geometrical similarity also is a necessity for even approximate results. Further, it is claimed that the data permits the prediction of changes in statical stability due to changes in hull dimensions and coefficients. As the range of dimensions and hull coefficients found in normal hull forms still had not been covered, continuation of the investigation in the same form was recommended. It was further recommended that the effect of sheer, the shape of the above-water body, and the shape of stern sections be investigated.

Later in 1948, in an M.I.T. thesis titled, "A Method of Predicting Statical Stability for Hull Coefficients", Messrs. Taylor, Ballantine and Reitz continued the study of Kelley et al. and Randall et al. Integration of two more hulls was completed, making a total of eight in all for which stability data was now available. In order to present the accumulated data in convenient form it was plotted as a set of contours of GZ/B versus the angle of inclination and a derived parameter C_W^3/C_B. Inconsistencies developed in the contours when plotted in this manner which Taylor et al. believed were due to inconsistencies in the variation of the coefficients of the hulls previously developed resulting in a series of unrelated hull forms. The authors therefore concluded that the hull forms must be truly related in order that the

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data obtained might be correlated and plotted in useful form. This led to the development of a new series of hull forms characterized by a uniform variation in hull coefficients, of which six hulls were delineated by means of Taylor's Mathematical Lines. Apparently time did not permit the integration of the new series of hulls to obtain stability data. The authors recommended integrating these hulls and continuing the pursuit of the statical stability curve by means of their method.

In 1949, Messrs. Church and Robinson continued the work of predicting statical stability in an M.I.T. thesis entitled, "The Estimation of Transverse Statical Stability from Form Coefficients and Principal Dimensions". As suggested by Messrs. Reitz et al. they integrated for stability data the six hulls previously delineated from Taylor's Mathematical Lines. This, plus all available stability data from past theses, was then plotted on a common basis in an attempt at correlation. It was found impossible to combine data from hulls of various characteristics into one integrated compilation that could be used for the practical determination of statical stability. From this the authors derived the conclusions that: (1) the Reitz parameter $(C_W)^{3/2}/C_B$ was not a suitable coordinate for use in plotting statical stability and (2) that in order to present a compilation of stability data in a usable form the data must be derived from a series of hulls belonging to a geometrical family which is allowed to vary only in one major characteristic at a time. Accordingly a new series of stability hulls based on Taylor's Standard Series was commenced. By ingenious longitudinal and transverse expansion processes Church and Robinson derived stability data for twelve different geometrically related forms from the integration of one parent hull.

In the belief that previously used parameters were unsatisfactory for use in plotting stability data the authors became interested in the residuary stability lever method of Prohaska. Their data plotted in this manner gave fair curves and appeared to be a practical solution to the problem. Accordingly the recommendation was made to continue the work along this same line.

In continuing the work of developing a method for predicting statical stability of a vessel in the preliminary design stage the present writers commenced by making a comprehensive review of the foregoing theses for the purpose of discovering, if possible, reasons for apparent disagreement among the various authors. Particularly it was desired to find the basic parameters best suited for presenting statical stability data in a form that can be readily used in preliminary design work, and to decide upon a basic hull form that would be suitable as a parent for a series of data.

It has been concluded that the primary reason for inability to successfully integrate the data of all past investigators into one series is, as Church and Robinson decided, due to the introduction of too many variables when a heterogeneous group of hull forms is used.

In order to plot data from various sources on a common coordinate system the parameters used must represent all of the factors involved in the relationship between dependent and independent variables. As applied to stability data if the righting arm is the ordinate the parameter used for the abscissa must include all factors influencing stability that are allowed to vary under the given conditions, and furthermore all factors included in the abscissa parameter must be unique functions of each other. It was possibly a realization of this theorem that prompted several previous investigators to

conclude that hull forms analyzed for a compilation of stability data must be geometrically related. They not only must be geometrically related, but when the parent characteristics are varied the variation must be completely expressible by a single parameter.

It has been further concluded that if a truly geometrically-related series of hull forms is employed in deriving stability data the results can be plotted in a satisfactory manner using only the elementary dimensions and form coefficients used in the usual definition of hull characteristics.

III PROCEDURE

In view of the foregoing conclusions relative to the necessity of employing a geometrically related series of hull forms attained by varying only one hull parameter at a time, it first became necessary to decide which and how many of the various hull dimensions and coefficients are necessary to sufficiently define the form characteristics contributing to statical stability, and then to determine how best to allow these parameters to vary in changing the shape of the hull.

It is of course well known that statical stability is determined by just two basic factors: (1) the position of the center of buoyancy of the portion of the hull immersed at a given angle of inclination, and (2) the position of the center of gravity of the weight of the entire ship. The latter remains fixed with respect to the hull as long as no weights are moved and may be approximated or determined by well-known methods. It is the influence on statical stability of the position of the center of buoyancy that we are interested in here. For any given attitude of a ship the position of the center of buoyancy depends entirely upon the shape of that part of the hull immersed at the time. Therefore in order to express statical stability in terms of hull dimensions and coefficients it is necessary to be able by their use to define the entire part of the hull that may be immersed within the range of inclinations for which stability data is desired. This in effect is the entire watertight hull structure.

In the preliminary design stage it is customary to determine

values for the following principal hull dimensions and coefficients of form:

LWL, length on the waterline

B, maximum beam

H, mean draft

D, depth amidships

SHEER, variation in depth along the length of the ship usually given as the difference between the depth amidships and the depths forward and aft

C_B block coefficient

C_P longitudinal prismatic coefficient

C_V vertical prismatic coefficient

C_X midship section coefficient

C_W waterplane coefficient

Thus there are available ten factors for defining hull form in stability data. To use them all would result in too large a number of parameters for a practicable system of stability prediction. Therefore, the following were selected as permitting a combination of sufficient definition of hull form and simplicity of presentation:

(1) D/B, depth-beam ratio

(2) H/D, draft-depth ratio

(3) C_p , longitudinal prismatic coefficient

Sheer also is used as a determining factor in the final predicted stability values, but is introduced in the form of a correction to D/B and H/D.

The reasons for omitting some and including others of the ten factors are as follows: Length was omitted because when righting arm is used as the measure, statical stability is independent of length. Beam, draft and depth are all considered to have major influence on statical stability. It should be noted that depth and sheer are the only factors pertaining to that part of the hull above the upright waterline, a part which influences stability at large angles as much as the underbody. The only justification for hoping to attain satisfactory results with such a meager description of the upper body is that for ships of normal form, to which this method must certainly be limited, the shape of the upper body follows pretty closely from a given underbody shape. The underbody shape in turn is of course closely defined by the form coefficients. The selection of the longitudinal prismatic coefficient as the one most suitable, was based on the fact that it is a measure of the longitudinal distribution of displacement. As such it is the best measure of the fullness of the various waterplanes developed as a ship takes successively increasing inclinations. The shape of the waterplane at a given angle of inclination is a very important factor in the determination of the statical stability at that angle. The decision not to try to incorporate more of the form coefficients into the method was based on many considerations. First, it was recognized that to develop a workable method for predicting statical stability in the preliminary design stage using more than three independently varying parameters would require more time than would be available. Second, it has been observed that the midship section coefficient of normal form merchant vessels varies but slightly. If the midship section co-

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efficient is a constant for various forms, the block coefficient becomes a direct function of the longitudinal prismatic coefficient. Therefore under these circumstances the midship section and block coefficients may be eliminated from consideration. Third, a comparison of lines drawings indicates that the shape of transverse ship sections has become pretty well standardized for the average merchant ship type. It appears that changes in hull form are attained more by longitudinal relocation of transverse sections rather than actually making much change in the shapes of the sections themselves. If it may be assumed that this is the case, then the vertical prismatic and waterplane coefficients become direct functions of the longitudinal prismatic coefficient. Thus by a series of assumptions the number of independently varying form coefficients has been reduced to only one, the longitudinal prismatic coefficient, C_p.

In order to make possible the final presentation of the stability data in dimensionless form draft, depth and beam were combined into the ratios H/D and D/B.

After considerable investigation into past ways of expressing statical stability it was decided to employ the simple ratio of righting arm divided by the ship's beam as the stability parameter. Furthermore, the righting arm is here measured from the keelpoint, K instead of from an assumed position of the center of gravity, in order to remove entirely any reference to the weight of the ship, which is not a factor in the purely hydrostatic contribution to stability. In addition this removes any possibility of confusion as to the position of an assumed center of gravity.

Reference (6) recommended the use of the Prohaska residuary stability lever method of presenting stability data, wherein the

righting arm, GZ, is expressed in terms of the initial metacentric height and a residuary factor as follows:

$$GZ = GM \sin \theta + MS$$

The present authors could see no rational basis for including initial metacentric height in a method where the stability data is obtained by integration of the hull form. It appears that nothing is gained thereby except an additional source of error. To calculate the position of the initial transverse metacenter using only the principal dimensions and hull coefficients available before delineation of the lines means determining first the position of the center of buoyancy by an approximate method such as that of Morrish, and then calculating an approximate metacentric radius using an assumed waterline inertia coefficient. Then the determination of the residuary stability lever, MS, by integration of hull forms is still subject to all of the assumptions previously mentioned in connection with the development of the present method. Also the present authors prefer to completely divorce metacentric height from the determination of the statical stability data thereby leaving metacentric height as an independent factor that can be used, if desired, to check the initial slope of the curves of statical stability predicted from the integrated data.

As a result of the foregoing considerations, the procedure decided upon for determining data for and presenting the method of predicting statical stability was briefly as follows: A study was made of the range of principal dimensions and longitudinal prismatic coefficients including the majority of common merchant vessel types and the following limits determined for data collection:

C_p 0.55 to 0.80

H/D 0.45 to 0.80

D/B 0.52 to 0.90

The body plan of a parent hull was drawn using a set of offsets from Taylor's Standard Series (Figure XX). This was integrated for sectional areas and moments of area using ten station spacings, five waterlines and six angles of inclination up to 90 degrees. Although the general intent was to collect data that could be combined with that of Reference (6) to become part of one method, it appeared that better accuracy could be obtained by increasing by one the four waterlines and up to 90 degrees the range of inclinations used by the authors of Reference (6). Areas and moments were integrated by Simpson's Rule and righting arms determined. The data derived from the parent hull was expanded by the methods of longitudinal and transverse expansion of Reference (6) to cover the desired range of parameters. This in effect resulted in obtaining statical stability data for twelve different hull forms each at five different drafts. For each of these forms, cross curves and curves of statical stability (Figures XXVI to XXXVII) were drawn to check for fairness and to aid in getting the data into the form desired for final presentation. The resulting stability data diagrams (Figures II to XVI) are explained under "Results" and the details of the procedure are given in the Appendix, part B.

It may appear to the reader that an undue number of simplifying assumptions have been made in deriving the procedure. In answer to this it must be remembered that the primary purpose of this method is to provide a quick way of approximating a curve of statical stability

for a ship before the lines drawings have been made. At this stage of the design procedure, uncertainty as to the location of the center of gravity of the weight of the ship as well as the lack of exact delineation of hull shape would nullify any attempt to attain a high degree of accuracy in the hydrostatic contribution to statical stability. Furthermore a more complicated method for use under the circumstances, but claiming greater accuracy would hardly be warranted if the labor involved in making a prediction thereby approached the work of a standard statical stability calculation. Lastly, the proof of the pudding is in the eating. As will be seen later in the discussion of results, stability data predicted by this method for vessels in existence shows satisfactory correlation with stability data calculated in the usual manner.

IV RESULTS

The results of this thesis are twofold. First, there has been produced a set of stability data designed to augment the work of Reference (6) in the development of a large scale project for the prediction of the statical stability of ships. Second, there has been developed a practical system for the graphical presentation and application of stability data for the purpose of predicting the statical stability of a ship in the preliminary design stage before the lines drawing have been made.

The first mentioned stability data is presented in tabular form in Table I and also in graphical form in the cross curves of stability on the left half of Figures XXVI to XXXVII. This data consists of ratios of righting arm divided by beam ($^{KZ}/B$) for Taylor's Standard Series hull forms inclined to various angles. For each hull form, the longitudinal coefficient used was that computed for the waterline which gave a draft-depth (H/D) ratio of 0.625. D was held constant at 6.4".

The data is for four different longitudinal prismatic coefficients of 0.55, 0.64, 0.71 and 0.80; a draft-depth ratio of 0.625, and three depth-beam ratios of 0.52, 0.64, and 0.90. In effect this represents data for 12 different, but geometrically related hulls, each having a designed draft-depth ratio of 0.625. It should be noted that the curves of statical stability on the

right side of Figures XXVI to XXXVII are not for the foregoing basic draft-depth ratios. These curves were drawn in developing the system of predicting statical stability which now will be explained as the second part of the results.

The second part is a fulfillment of the authors' desire to develop a method for using an accumulation of stability data to actually predict a curve of statical stability using only the principal dimensions and form coefficients of a ship. Although the method as presented here is complete in itself for use over an extensive range of ship forms it must be emphasized that due to certain assumptions made in expanding and interpolating data into a form convenient for use, the accuracy is probably not as great as can be attained by utilizing a more extensive collection of basic data. In other words here we present an idea ratherthan a completely finished product. However, as will be seen in the discussion of results, even with the basic data spread pretty thin some very encouraging results are obtained.

The second part of the results consists of a set of diagrams by means of which if the principal dimension, longitudinal prismatic coefficient, and estimate of the vertical position of center of gravity of a merchant ship of usual form are known, a predicted curve of statical stability may be constructed. There are fifteen diagrams each giving the relation between a stability parameter, $^{KZ}/_{B}$ and the longitudinal prismatic coefficient, C_p for six different angles of inclination. (Figures II to XVI). Each diagram is for a given value of draft-depth ratio, (H/D) and depth beam ratio, (D/B). Interpolation may be used to obtain stability

parameter data for values of H/D and D/B between the tabulated values. The range of ship forms covered by the system includes longitudinal prismatic coefficients from 0.55 to 0.81, H/D ratios from 0.45 to 0.80 and D/B ratios from 0.52 to 0.90, which were selected to include the majority of normal-form merchant vessels. In addition to the fifteen diagrams there is a longitudinal prismatic coefficient correction curve, the use of which will be described in the explanation of how to use the method for predicting a curve of statical stability.

In the interest of simplification the procedure for utilizing the method will be given first without the reasons or theory for various steps, which will be discussed later. It is most convenient to use a form such as used for the sample calculation in Table II.

The following required preliminary design information is first obtained for the ship in question and entered in the appropriate spaces on the upper left side of the form: beam (B), draft (H) at a given displacement (Δ), depth of hull amidships (D), sheer as measured by the increases of depth forward and aft above that amidships, the longitudinal prismatic coefficient corresponding to the given displacement, and the estimated vertical position of the center of gravity of the vessel (KG). Next correct the prismatic coefficient by entering the prismatic coefficient correction curve (Figure I) with the H/D ratio and selecting the corresponding C_p correction factor which when when multiplied by the original C_p gives the corrected value of C_p for use when entering the stability parameter diagrams. In order to account for the contribution of

sheer to the curve of statical stability the depth amidships is changed to a new value by means of the following equation:

$$D \text{ corrected} = \frac{SF + SA}{6} \times C_p \text{ corrected} + D \qquad (1)$$

where: SF = sheer forward in feet
SA = sheer aft in feet

With the corrected value of D calculate H/D and D/B. The values used for arguments in entering the stability parameter diagrams are: the corrected C_p, and the values of H/D and D/B calculated with the value of D corrected for sheer. In general the H/D and D/B values will fall between the tabulated values. Therefore, a double interpolation will be required as indicated in the example calculation (Table II). The result will give values of righting arm divided by beam ($^{KZ}/_{B}$) for the six angles of inclination listed. To get values of righting arm referred to the estimated vertical location of the center of gravity the following equation is used:

$$GZ = \left[{}^{KZ}/_{B}\right] \times B - KG \sin\theta \qquad (2)$$

where: GZ = the righting arm in feet

$^{KZ}/_{B}$ = the dimensionless stability parameter

B = the beam of the ship in feet

KG = the distance of the center of gravity of the ship from the base line in feet

θ = a given angle of inclination

This calculation may be performed as indicated in the tabular form of Table II .

An explanation of the C_p and sheer corrections will now be given. The values of longitudinal prismatic coefficient (C_p) used on the stability parameter diagrams are those for hull forms having assumed designed draft-depth ratio of 0.625. For example the diagram for D/B = 0.52 and H/D = 0.45 is strictly only for a hull form

with a longitudinal prismatic coefficient calculated for $H/D = 0.625$, but which is floating so that $H/D = 0.45$. Now if the ship for which a curve of statical stability is desired has a designed H/D of 0.45 and the known value of C_p is for that H/D ratio, it will be necessary to correct the C_p to the value it would have if the ship were floating at an H/D of 0.625 in order to use the diagrams correctly. The prismatic coefficient correction curve gives the approximate correction. It is approximate because the curve is based on the change of C_p with draft-depth ratio for a Taylor's Standard Series hull, which except for coincidence, will not be identical with a ship picked at random.

The necessity of a correction for sheer is of course obvious. When the deck edge becomes immersed progressively deeper the greater the positive sheer the greater will be the righting moment arm of the immersed volume. Basically equation (1) is derived from the area between the outside of a parabola and its enclosing rectangle which is equal to 1/3 of the area of the rectangle. Assuming then that the sheer curve is parabolic, the transverse projection of the hull area above a horizontal line through the point of least depth is approximately equal to the sum of the sheer forward and aft divided by six. If the ship were parallel-sided like a barge, the effect of sheer on the righting arm would be very nearly the same as adding a constant increase of depth equal to that amount. However, the fineness of a ship's ends slows the progressive immersion of the deck edge at a given rate of inclination. Similarly, this fineness reduces the effectiveness at large angles of inclination of the sheer as an augmentation to righting arm. Therefore, the correction derived purely on the parabolic area basis requires a further reducing correction roughly proportional to the amount of

fineness. Since the longitudinal prismatic coefficient is approximately proportional to this fineness at the ship's ends, it was introduced as a factor in the correction for sheer.

TABLE I

VALUES OF KZ/B FOR THE BASIC DRAFT-DEPTH RATIO, H/D = 0.625

B = 7.12"

	C_p = 0.55, ∇ = 216		C_p = 0.64, ∇ = 252		C_p = 0.71, ∇ = 279		C_p = 0.80, ∇ = 315	
θ	KZ	KZ/B	KZ	KZ/B	KZ	KZ/B	KZ	KZ/B
20.7	1.16	.163	1.17	.164	1.17	.164	1.17	.164
39.1	2.23	.313	2.16	.304	2.22	.312	2.22	.312
54.6	2.89	.406	2.88	.405	2.88	.405	2.90	.408
67.7	3.31	.465	3.32	.466	3.29	.452	3.29	.452
79.2	3.51	.493	3.50	.492	3.45	.485	3.45	.485
90	3.58	.503	3.53	.496	3.48	.489	3.41	.479

B = 10.00"

	C_p = 0.55, ∇ = 304		C_p = 0.64, ∇ = 354		C_p = 0.71, ∇ = 392		C_p = 0.80, ∇ = 442	
θ	KZ	KZ/B	KZ	KZ/B	KZ	KZ/B	KZ	KZ/B
15	1.11	.111	1.14	.114	1.16	.116	1.16	.116
30	2.22	.222	2.26	.226	2.28	.228	2.31	.231
45	3.04	.304	3.07	.307	3.09	.309	3.10	.310
60	3.52	.352	3.50	.350	3.53	.353	3.49	.349
75	3.71	.371	3.73	.373	3.67	.367	3.62	.362
90	3.58	.358	3.53	.353	3.48	.348	3.41	.341

B = 12.30"

	C_p = 0.55, ∇ = 374		C_p = 0.64, ∇ = 436		C_p = 0.71, ∇ = 482		C_p = 0.80, ∇ = 543	
θ	KZ	KZ/B	KZ	KZ/B	KZ	KZ/B	KZ	KZ/B
12.3	1.14	0.93	1.18	.096	1.19	.097	1.20	.098
24.9	2.34	.190	2.26	.184	2.42	.197	2.38	.194
39.1	3.20	.260	3.23	.262	3.29	.267	3.33	.271
54.6	3.75	.305	3.76	.306	3.74	.304	3.70	.301
71.7	3.86	.314	3.91	.318	3.88	.316	3.79	.308
90	3.58	.291	3.53	.287	3.48	.283	3.41	.277

Table II

SAMPLE COMPUTATION

CALCULATION SHEET FOR PREDICTING A CURVE OF STATICAL STABILITY

Note: C_p corrected used in depth correction.

SHIP CHARACTERISTICS

Name	Victory Ship
Ship Type	Maritime Comm. VC2
LOA	455' 3"
LBP	436' 6"
LWL	
Beam, B	62' 0"
Draft, H at Δ = 11,600T	22' 6"
Depth amidships, D	38' 0"
Sheer (inc. of depth amidships) Fwd., S_F	4'
Aft, S_A	7'
Long. Prism. Coef., C_p	0.682
Height of c.g., KG	22.0'

CORRECTIONS

Sheer Correction:

$$D_{corrected} = \frac{S_F + S_A}{6} \cdot C_p + D$$

$$= \frac{4+7}{6} \cdot (0.692) + 38$$

$$= 39.27$$

Corrected H/D = 0.573

Long. prismatic coeff. correction from curve: H/D = 0.593

$$C_{p\ corrected} = (\cancel{1.104}\ 1.014)(.682)$$

$$= 0.692$$

$$GZ = \frac{KZ}{B} \cdot B - KG \sin\theta$$

(Assumed KG used in Cross Curves)

Parameters for entering diagrams: C_p = .692 ; H/D = .573 ; D/B = .633.

KZ/B for D/B = .52				KZ/B for D/B = .64			
θ	$\frac{H}{D}$ = .5	$\frac{H}{D}$ = .6	$\frac{H}{D}$ = .573	θ	$\frac{H}{D}$ = .5	$\frac{H}{D}$ = .6	$\frac{H}{D}$ = .573
15°	.112	.115	.114	15°	.114	.115	.115
30	.244	.226	.231	30	.231	.227	.228
45	.308	.290	.295	45	.325	.310	.314
60	.333	.315	.320	60	.370	.356	.360
75	.330	.315	.319	75	.382	.372	.375
90	.291	.286	.287	90	.358	.350	.352

θ	sin θ	$\frac{KZ}{B}$ for H/D=.573, D/B=.633	$KZ = \frac{KZ}{B} \cdot B$	KG sin θ	$GZ = KZ - KG\sin\theta$	GZ from Cross Curves
15°	0.259	.115	7.13	5.7	1.4	1.2
30	0.500	.228	14.15	11.0	3.1	2.8
45	0.707	.313	19.4	15.5	3.9	4.0
60	0.866	.358	22.2	19.0	3.2	3.6
75	0.966	.372	23.1	21.2	1.9	2.2
90	1.000	.348	21.6	22.0	- 0.4	0.6

E. C. Thompson, Jr., A. F. Hubbard

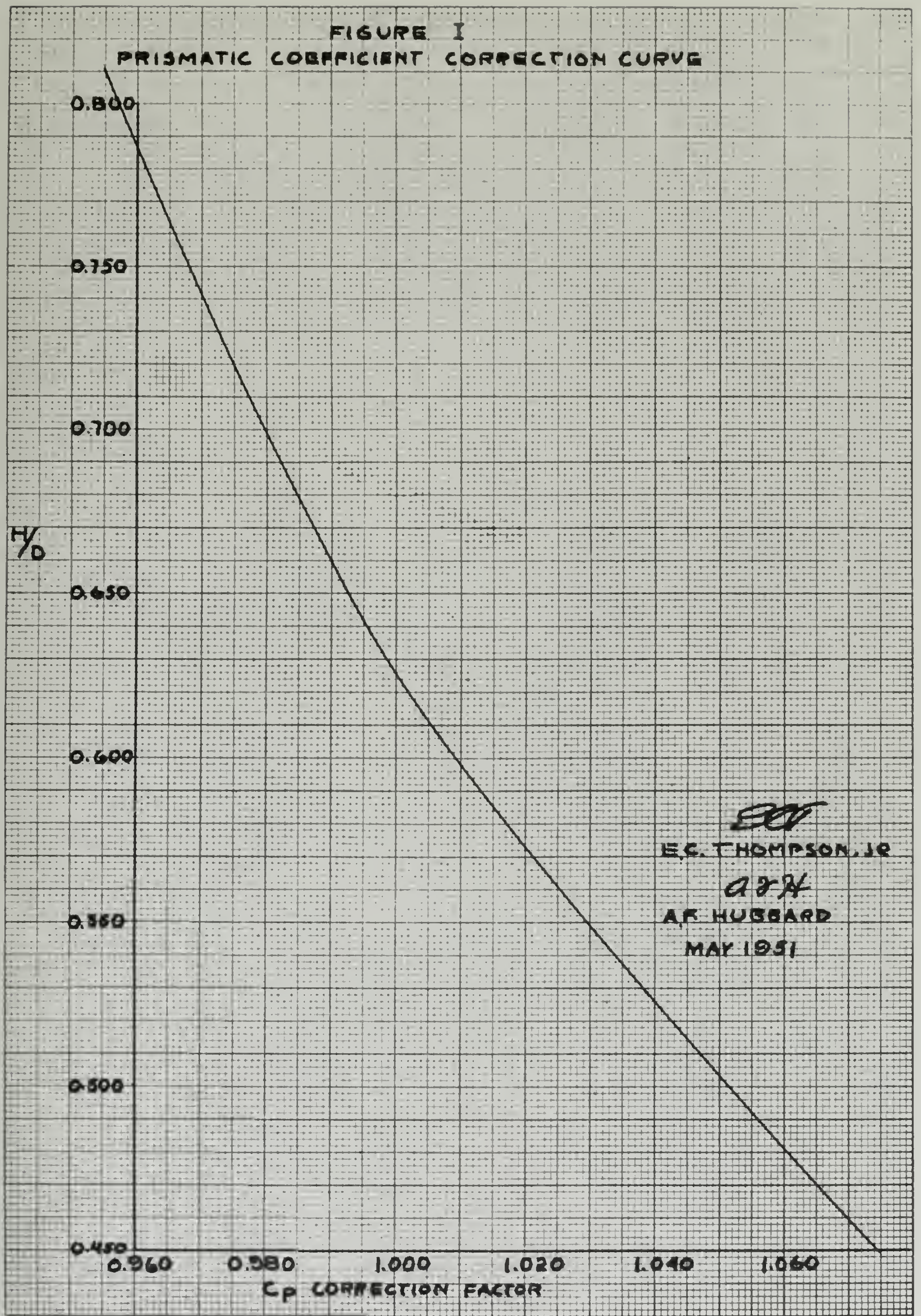


FIGURE I
PRISMATIC COEFFICIENT CORRECTION CURVE
H/D
0.800
0.750
0.700
0.650
0.600
0.550
0.500
0.450
0.960
0.980
1.000
1.020
1.040
1.060
Cp CORRECTION FACTOR
E.C. THOMPSON, JR
A.F. HUBBARD
MAY 1951

Figure II

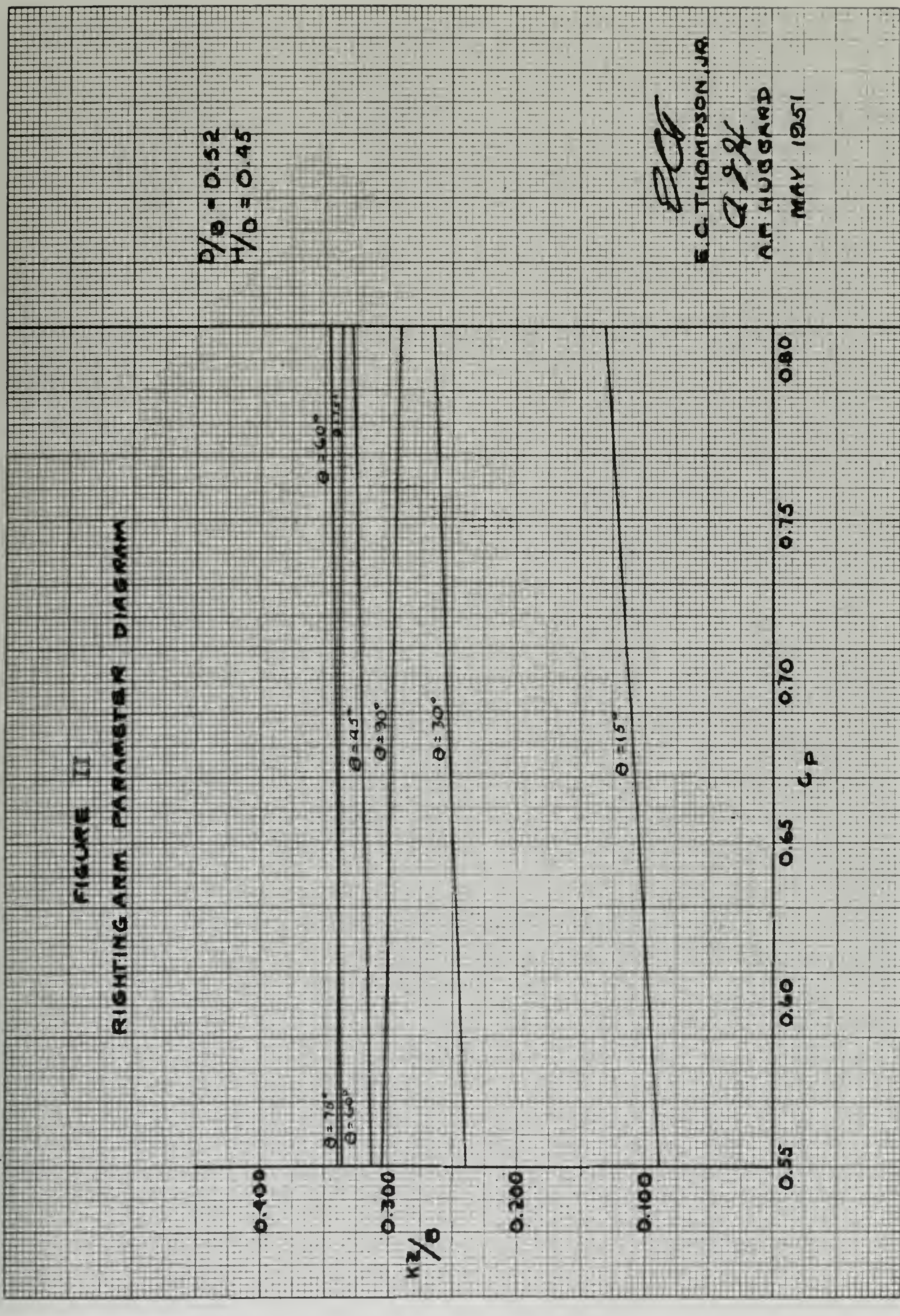


FIGURE II
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.52
H/D = 0.45
E.C. THOMPSON, JR.
A.M. HUBBARD
MAY 1951
0.400
0.300
0.200
0.100
KZ/B
0.55
0.60
0.65
0.70
0.75
0.80
CP
θ = 75°
θ = 60°
θ = 45°
θ = 30°
θ = 15°

Figure III

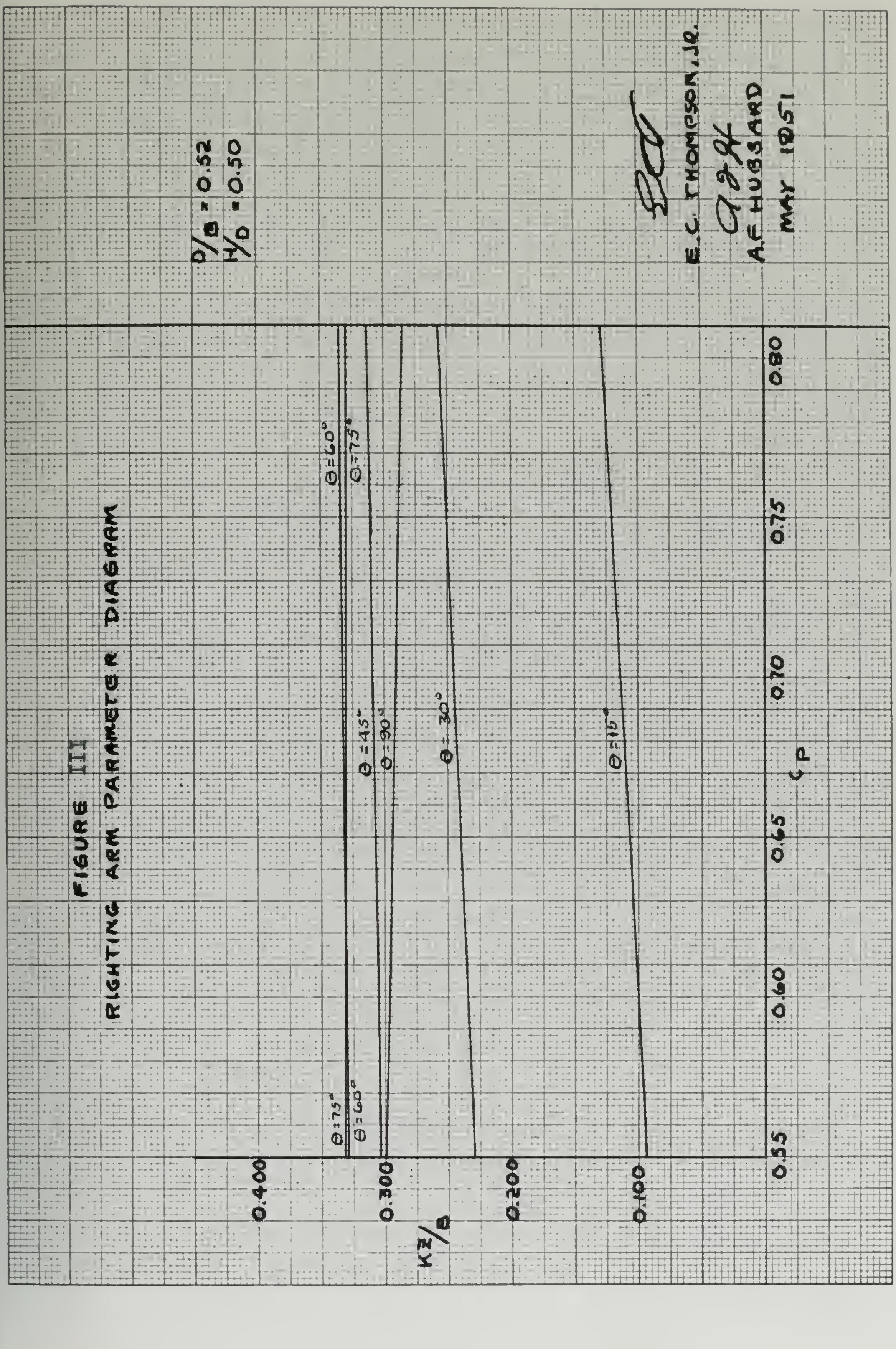


FIGURE III
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.52
H/D = 0.50
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951
KZ/B
0.400
0.300
0.200
0.100
0.55
0.60
0.65
0.70
0.75
0.80
C P
θ = 60°
θ = 75°
θ = 45°
θ = 90°
θ = 30°
θ = 15°

Figure IV

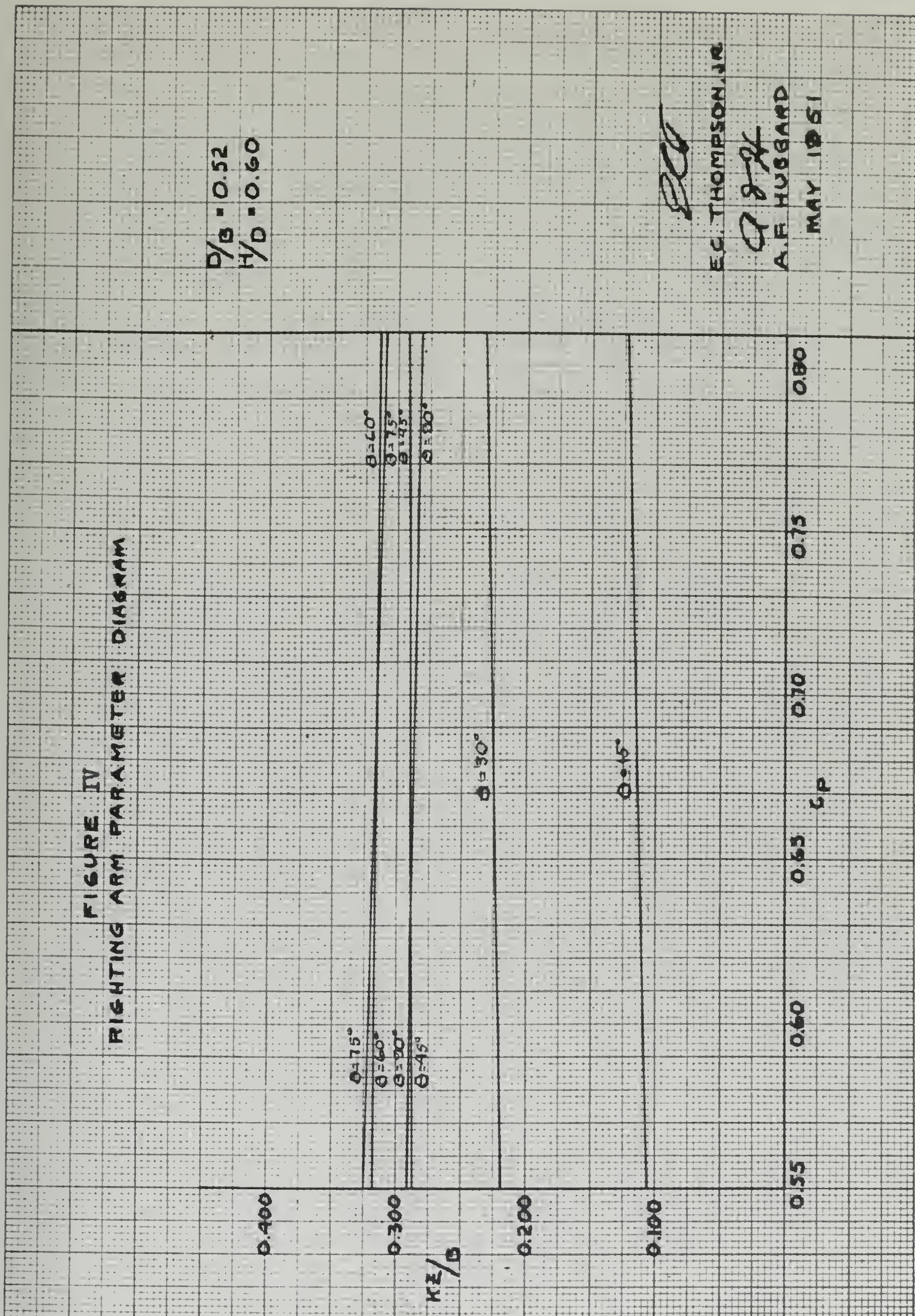


FIGURE IV
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.52
H/D = 0.60
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951
0.400
0.300
0.200
0.100
KZ/B
0.55
0.60
0.65
0.70
0.75
0.80
CP
θ=15°
θ=30°
θ=75°
θ=60°
θ=90°
θ=45°

Figure V

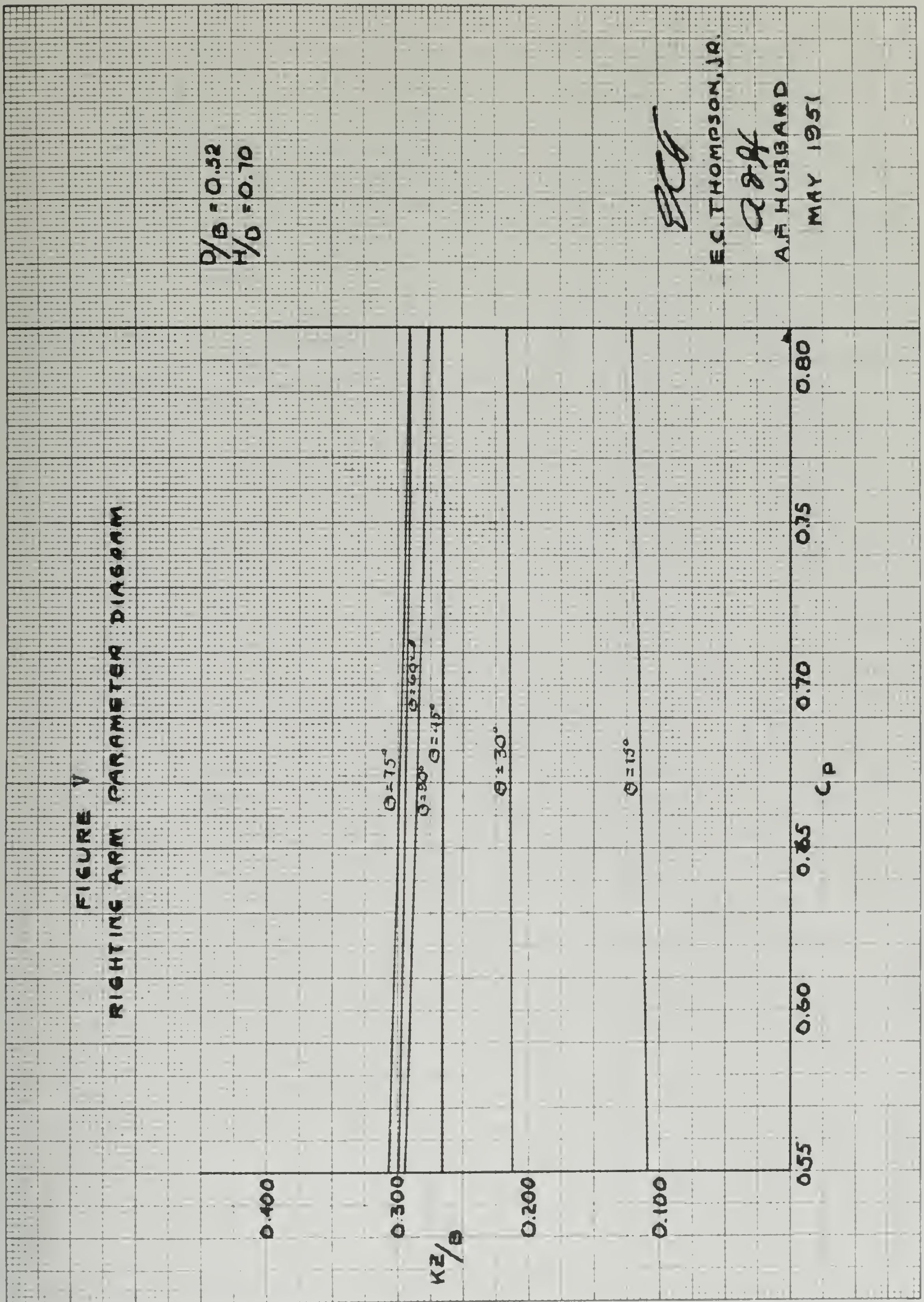


FIGURE V
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.32
H/D = 0.70
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951
θ = 75°
θ = 45°
θ = 30°
θ = 15°
0.400
0.300
0.200
0.100
KZ/B
0.55
0.60
0.65
0.70
0.75
0.80
Cp

Figure VI

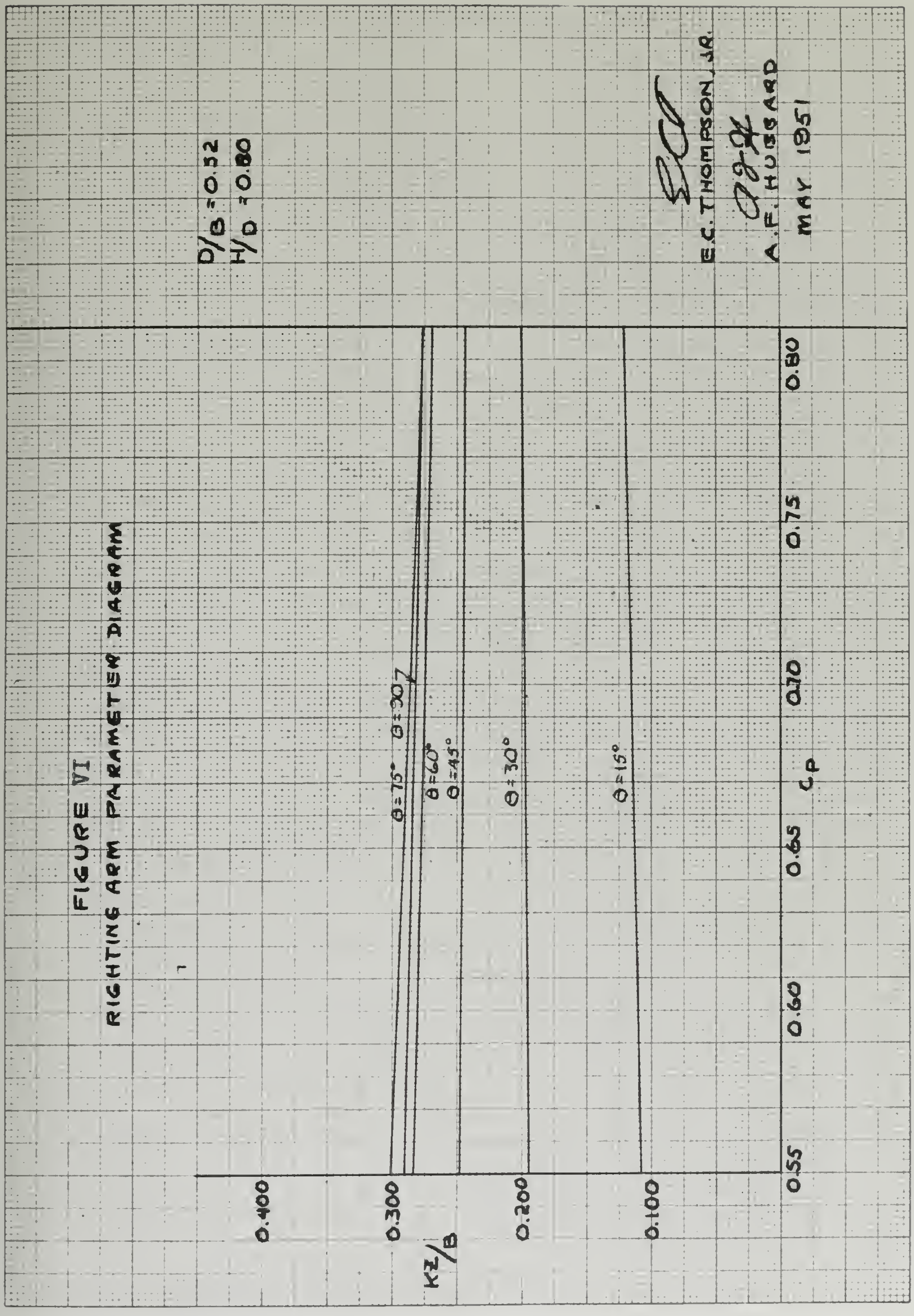


FIGURE VI
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.32
H/D = 0.80
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951
θ = 75°
θ = 90°
θ = 60°
θ = 45°
θ = 30°
θ = 15°
KZ/B
0.400
0.300
0.200
0.100
CP
0.55
0.60
0.65
0.70
0.75
0.80

Figure VII

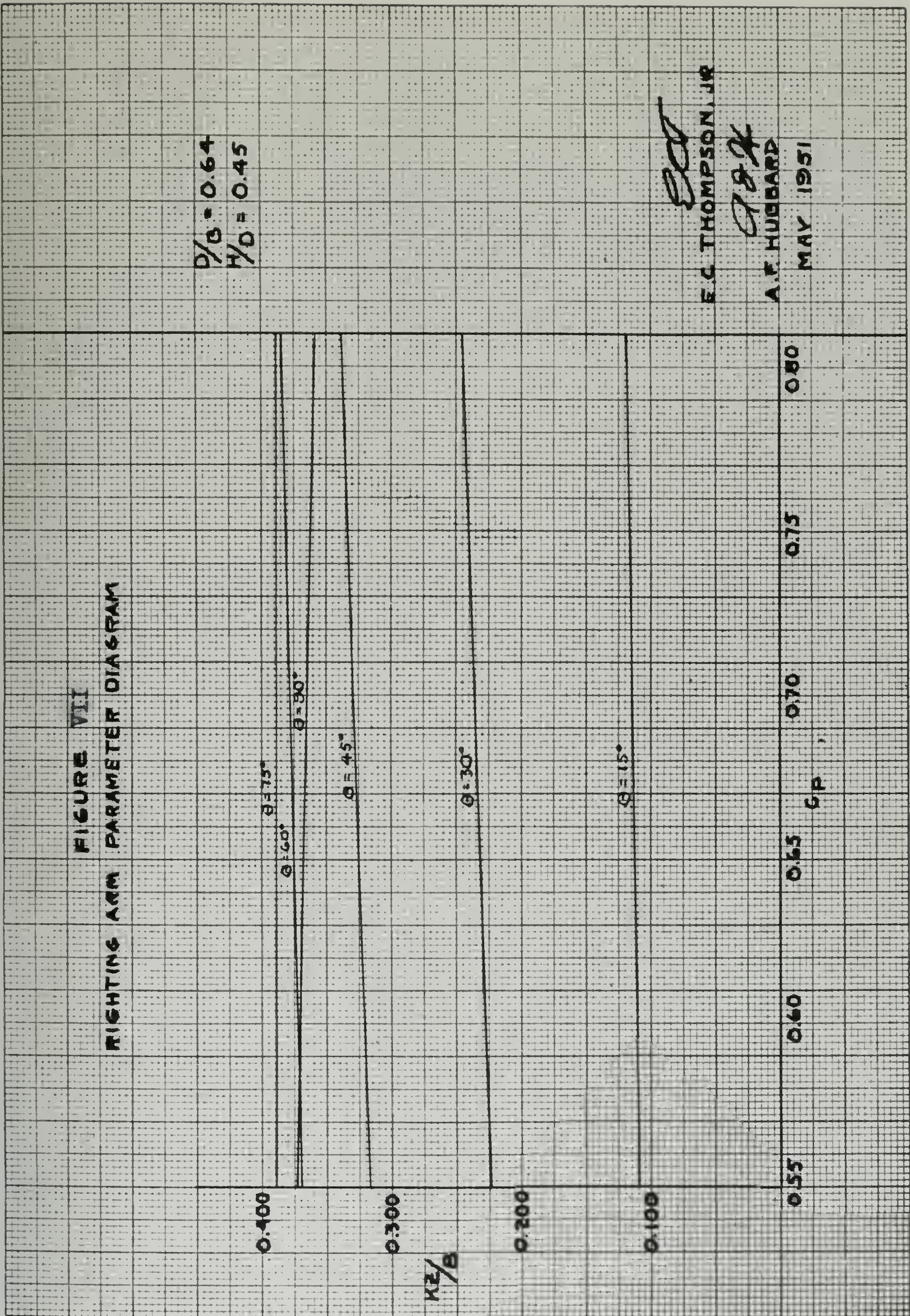


FIGURE VII
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.64
H/D = 0.45
E.C. THOMPSON, JR
A.F. HUBBARD
MAY 1951
θ = 75°
θ = 60°
θ = 90°
θ = 45°
θ = 30°
θ = 15°
0.400
0.300
0.200
0.100
KZ/B
0.55
0.60
0.65
0.70
0.75
0.80
Cp

Figure VIII

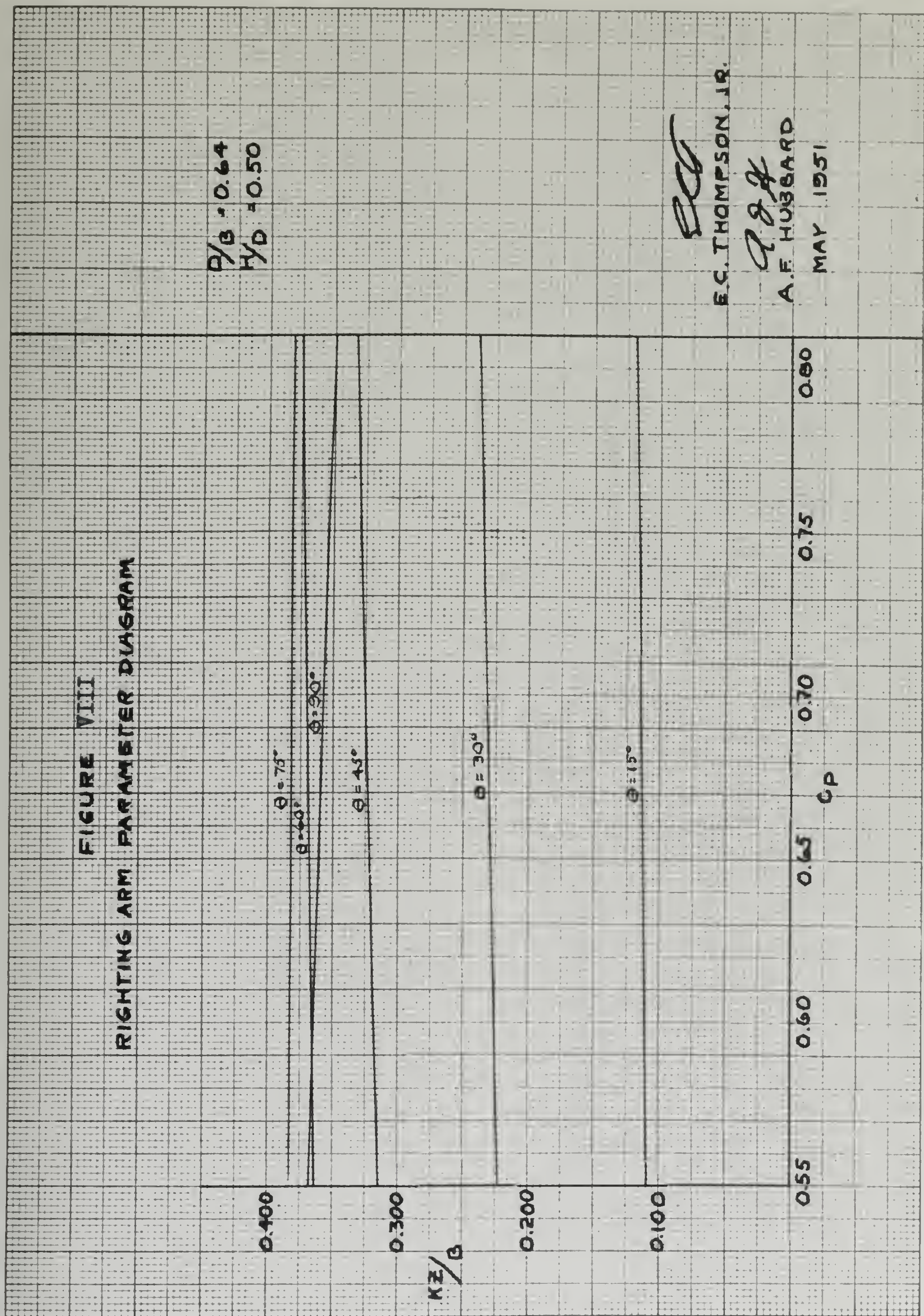


FIGURE VIII
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.64
H/D = 0.50
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951
θ = 75°
θ = 60°
θ = 90°
θ = 45°
θ = 30°
θ = 15°
0.400
0.300
0.200
0.100
KZ/B
0.55
0.60
0.65
0.70
0.75
0.80
Cp

Figure IX

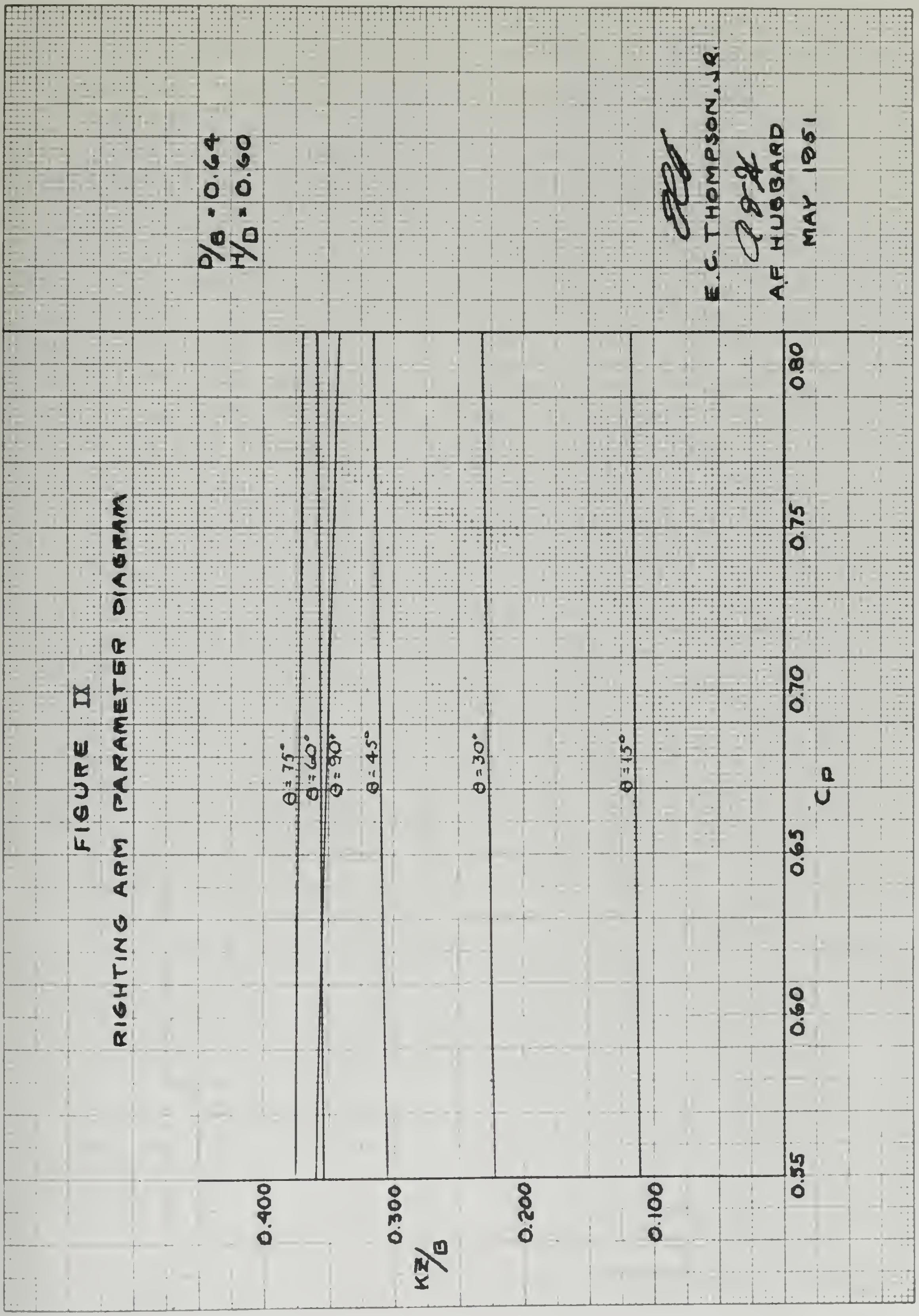


FIGURE IX
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.64
H/D = 0.60
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951
θ = 75°
θ = 60°
θ = 90°
θ = 45°
θ = 30°
θ = 15°
0.55
0.60
0.65
0.70
0.75
0.80
Cp
0.400
0.300
0.200
0.100
KZ/B

Figure X

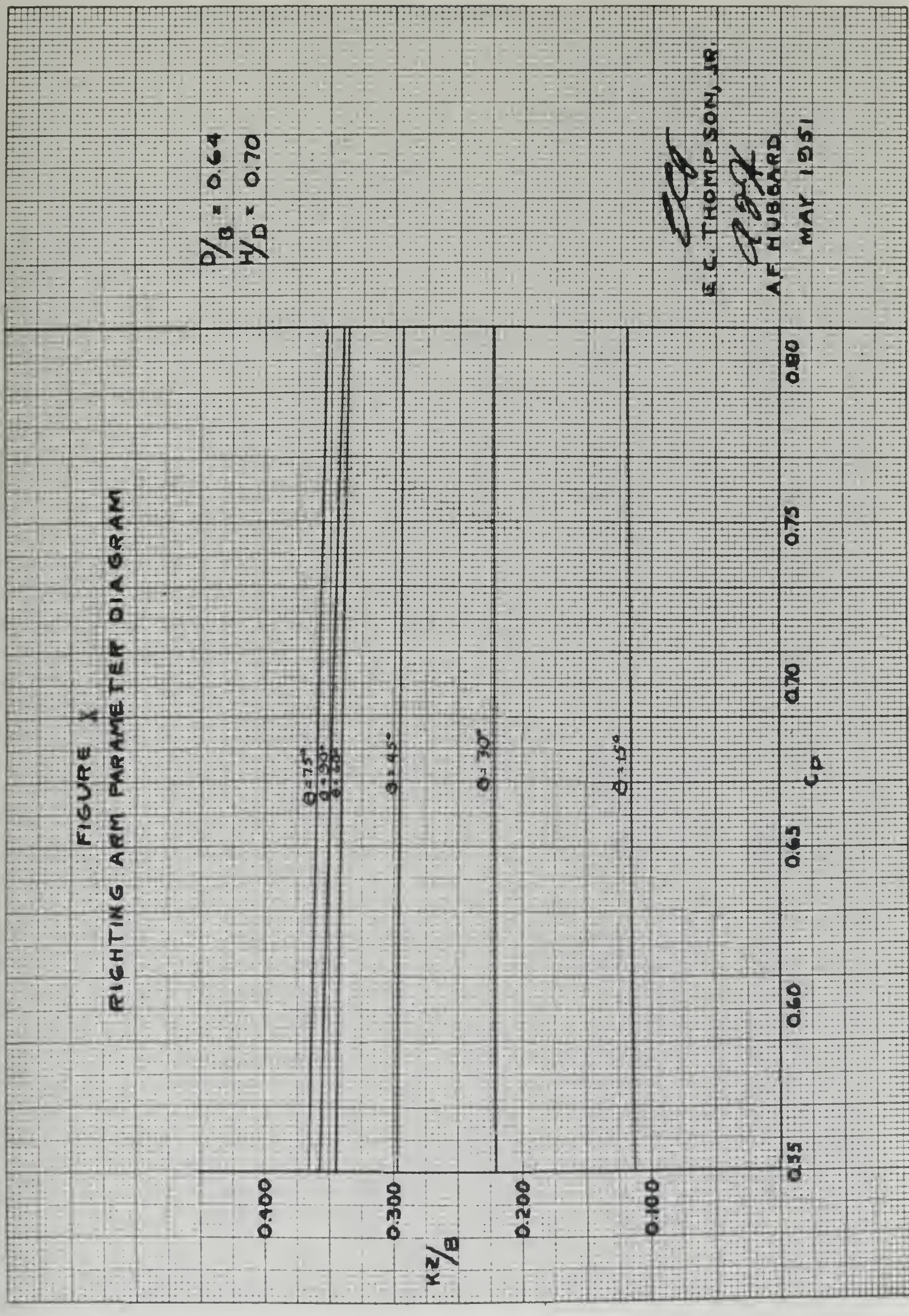


FIGURE X
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.64
H/D = 0.70
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951
θ=75°
θ=45°
θ=30°
θ=15°
0.400
0.300
0.200
0.100
KZ/B
0.55
0.60
0.65
0.70
0.75
0.80
Cp

Figure XI

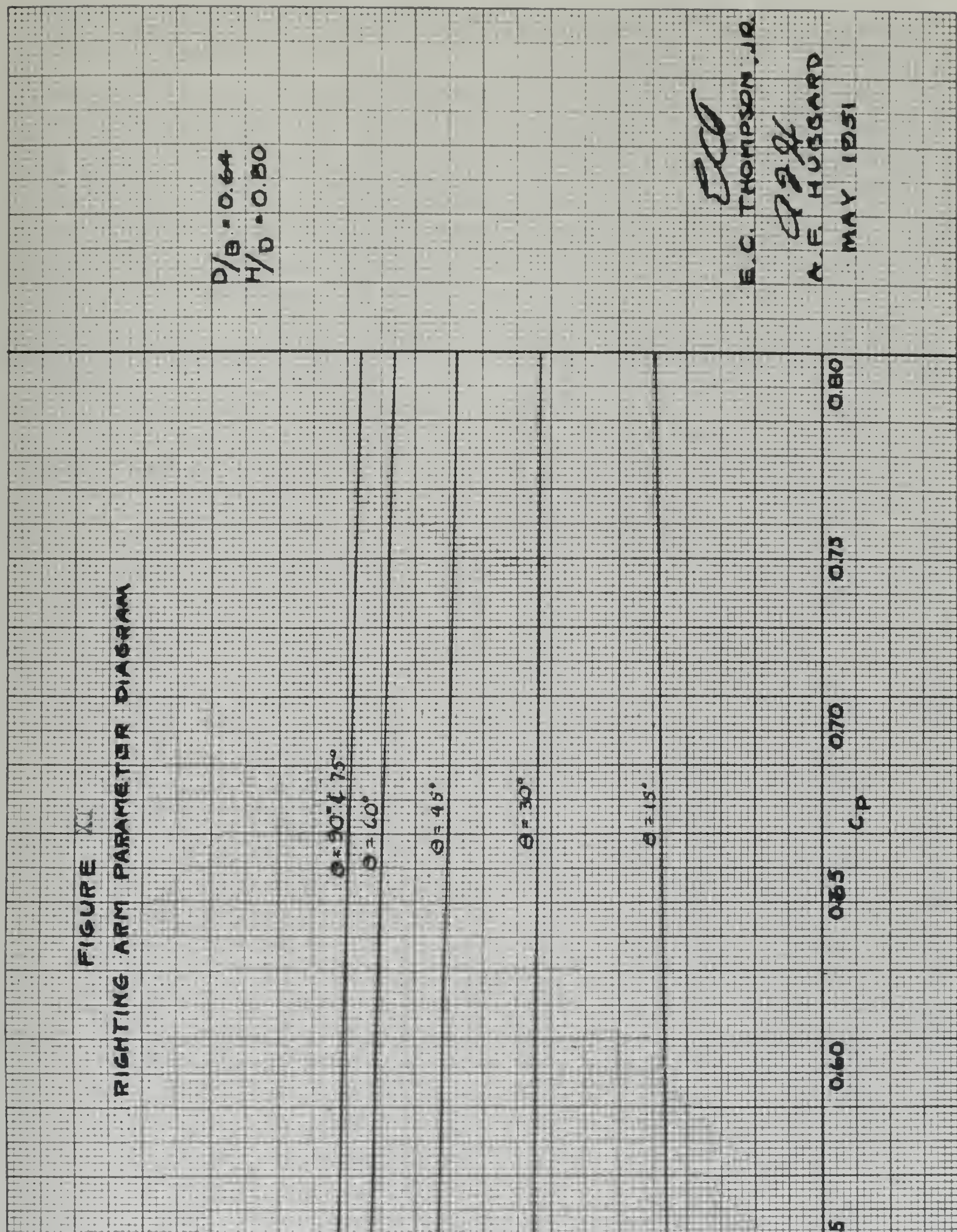


FIGURE XI
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.64
H/D = 0.80
E.C. THOMPSON, JR.
A.E. HUBBARD
MAY 1951
θ = 90° & 75°
θ = 60°
θ = 45°
θ = 30°
θ = 15°
KZ/B
0.400
0.300
0.200
0.100
C.P
0.55
0.60
0.65
0.70
0.75
0.80

Figure XII

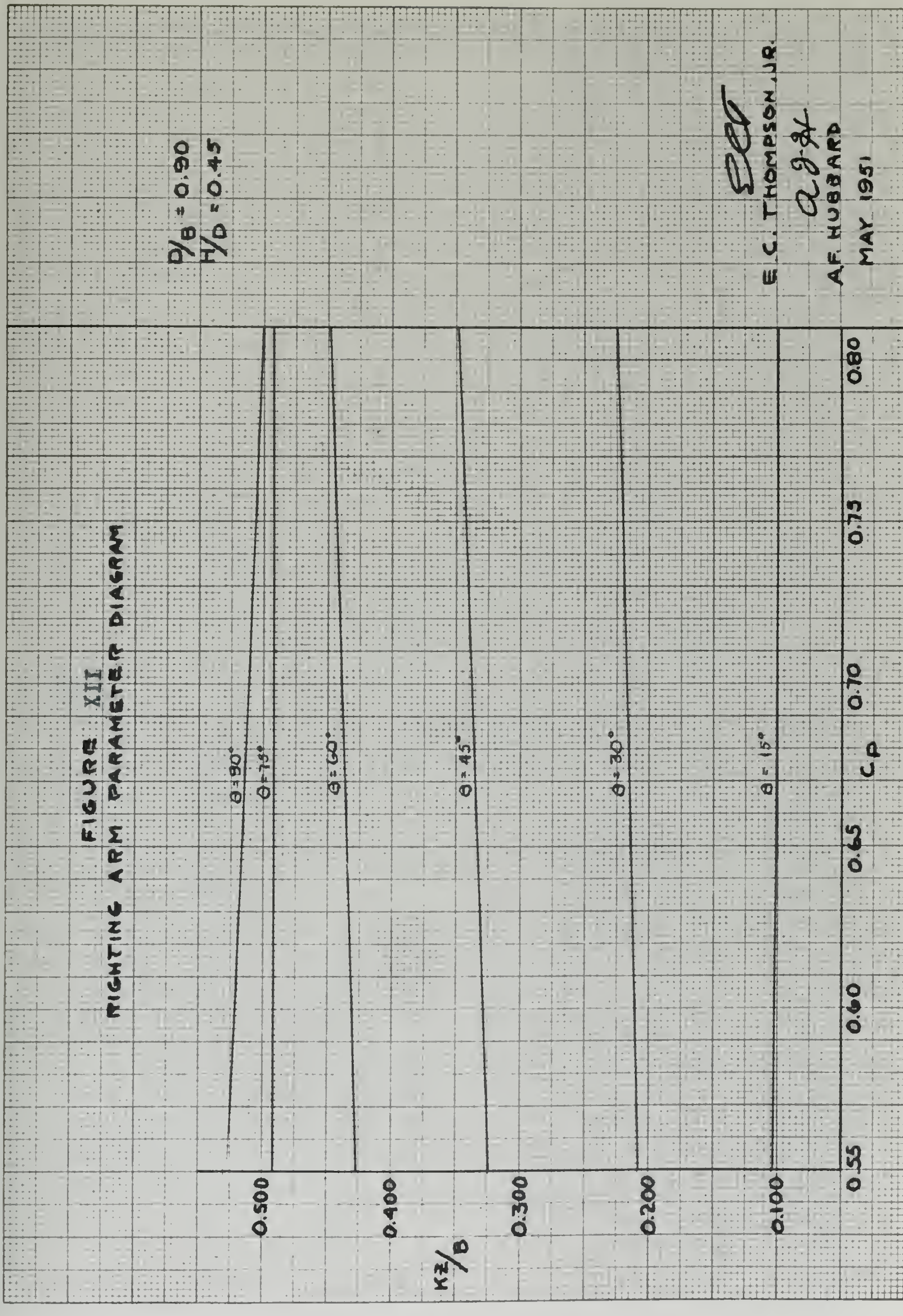


FIGURE XII
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.90
H/D = 0.45
θ = 90°
θ = 75°
θ = 60°
θ = 45°
θ = 30°
θ = 15°
0.55
0.60
0.65
0.70
0.75
0.80
C_P
0.500
0.400
0.300
0.200
0.100
KZ/B
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951

Figure XIII

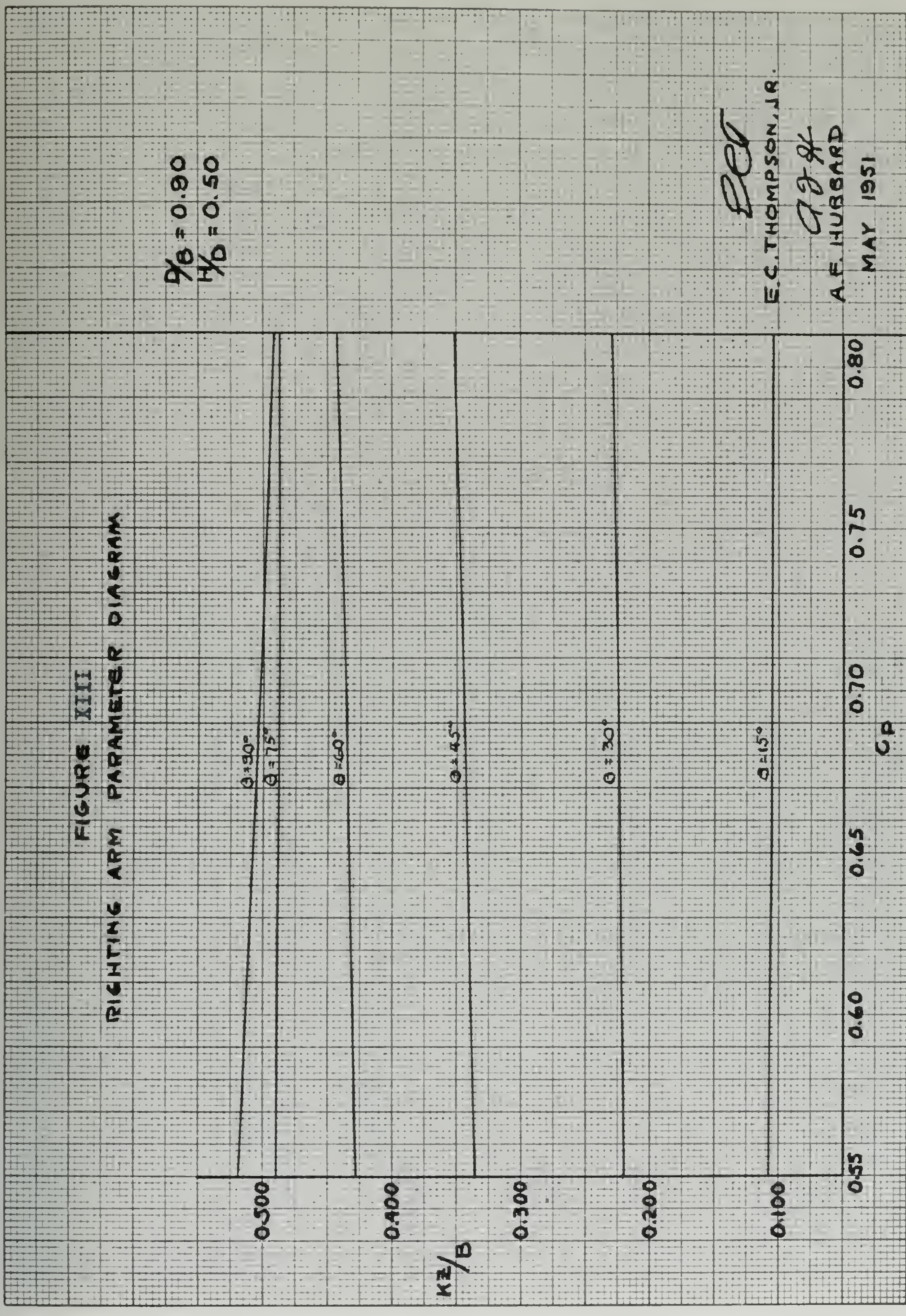


FIGURE XIII
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.90
H/D = 0.50
θ=90°
θ=75°
θ=60°
θ=45°
θ=30°
θ=15°
0.55
0.60
0.65
0.70
0.75
0.80
Cp
0.500
0.400
0.300
0.200
0.100
KZ/B
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951

Figure XIV

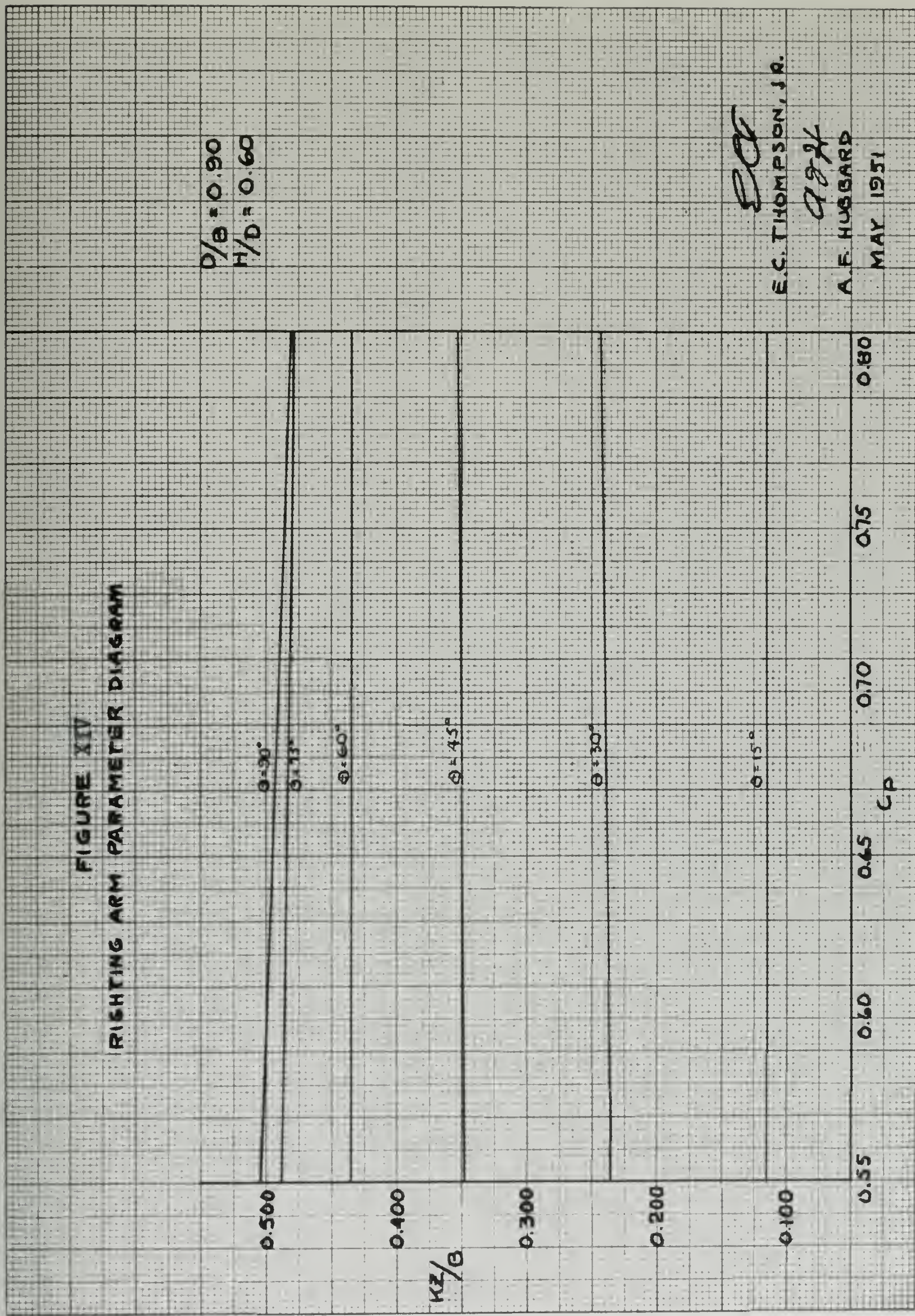


FIGURE XIV
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.90
H/D = 0.60
E.C. THOMPSON, JR.
A.E. HUBBARD
MAY 1951
θ = 90°
θ = 60°
θ = 45°
θ = 30°
θ = 15°
0.55
0.60
0.65
0.70
0.75
0.80
Cp
0.500
0.400
0.300
0.200
0.100
KZ/B

Figure XV

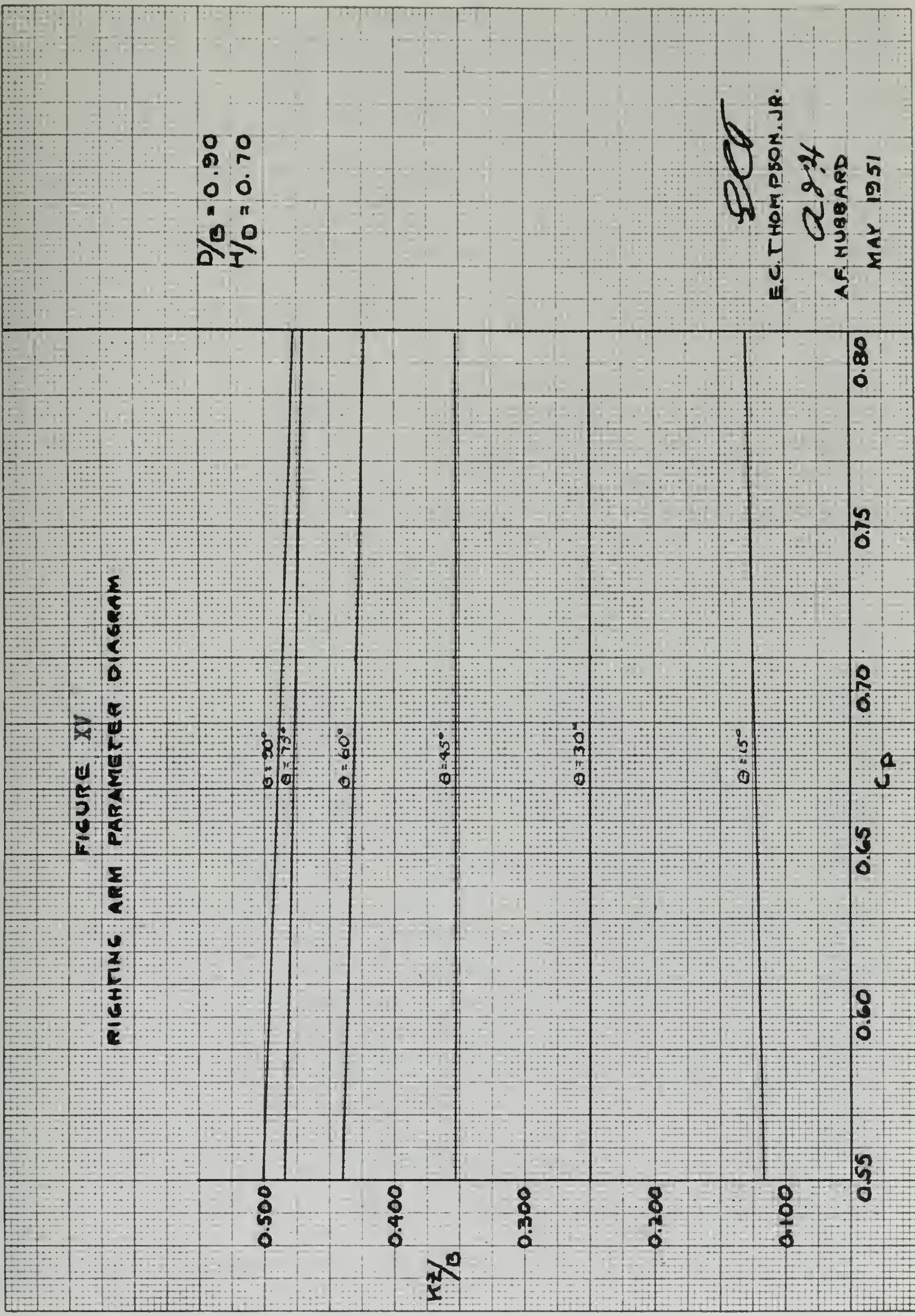


FIGURE XV
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.90
H/D = 0.70
θ = 90°
θ = 75°
θ = 60°
θ = 45°
θ = 30°
θ = 15°
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951
0.55
0.60
0.65
0.70
0.75
0.80
Cp
0.500
0.400
0.300
0.200
0.100
KZ/B

Figure XVI

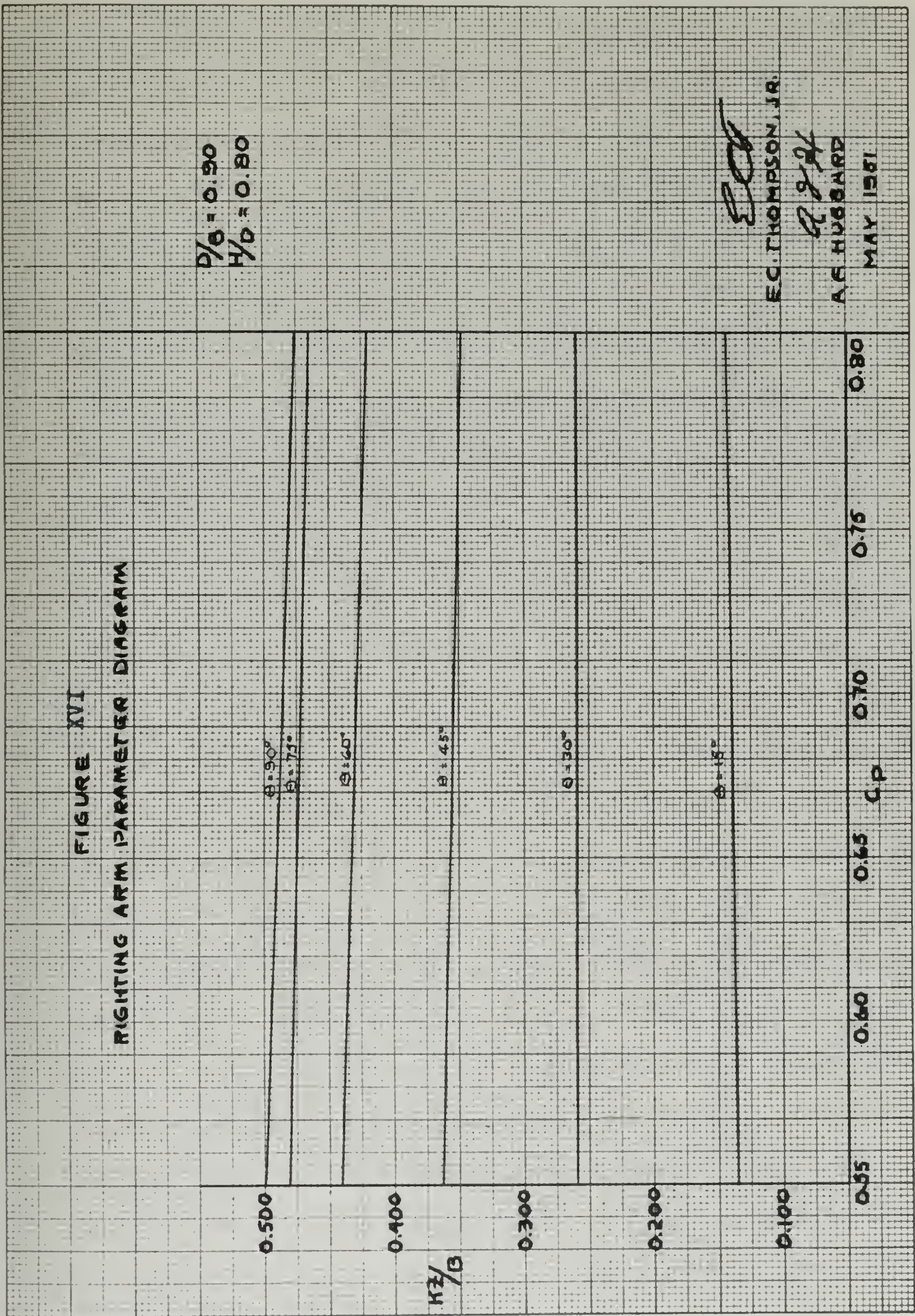


FIGURE XVI
RIGHTING ARM PARAMETER DIAGRAM
D/B = 0.90
H/D = 0.80
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951
θ = 90°
θ = 75°
θ = 60°
θ = 45°
θ = 30°
θ = 15°
0.55
0.60
0.65
0.70
0.75
0.80
Cp
KZ/B
0.100
0.200
0.300
0.400
0.500

The part of the results consisting of the set of stability data designed to augment the work of Reference (6) will be considered first. The accuracy of these data is considered to be at least as great as that of Reference (6). The present writers used five waterlines spaced one-half inch apart whereas the Reference authors used four waterlines spaced one inch apart when integrating for the basic stability data. This gave one more point for fairing in the cross curves of stability resulting in increased accuracy. Beyond this change it is believed that the procedures used for expanding the basic data to the various longitudinal prismatic coefficients and depth-beam ratios were in general the same as used by the authors of Reference (6). Using the accuracy of the basic data resulting from the integration of the parent form as a standard of comparison it is believed little, if any, accuracy was lost in the method used for expansion to the various longitudinal prismatic coefficients. This method, although graphical, was direct and required the drawing of a number of curves of sectional areas and moments of areas, the fairness of which curves served as a check on the accuracy of individual points. Also the cross curves of stability and curves of statical stability plotted from these data were satisfactorily fair. (Figures XXVI to XXXVII). However, the method used to expand the data to the different depth-beam ratios was not as straightforward. For instance, it required the determination of the perpendicular distance from the inclined waterline to the center of buoyancy of the immersed portion of the hull for each transverse expansion. (P_1B_1 values in Tables X to XIII). These values were found by drawing displacement curves for the inclined positions (Figures XXIII to XXV), then dividing the

areas above the curves by the corresponding volumes of displacement. In drawing these curves there was no displacement data available below the No. 3 W.L. which meant fairing the curves from there down to zero displacement by eye. Of course, there is not much variation possible in the shape of the curves between No. 3 W.L. and zero so that any error resulting from this source is probably not large. When the cross curves of stability and the curves of statical stability for the transversely expanded data were plotted they required considerably more cross fairing than for the original depth-beam ratio data, thus indicating that in fact there had been some error introduced. However, the cross fairing process between the two sets of curves should have removed most of the error from the final data.

Turning to the second part of the results, the best way to check on the reliability of the method devised for the prediction of a curve of statical stability is to try it. This was done for four ships, selected at random, for which standard cross curves of stability were available. Calculations for the prediction of the curves of statical stability were made using only the longitudinal prismatic coefficients and principal dimensions of the ships in question, exactly as could be done in preliminary design prior to delineation of the lines. Comparisons of the predicted curves and actual curves are shown on Figures XVII and XVIII. In each case the predicted curve and actual curve are for the same assumed vertical position of the ship's center of gravity.

A considerable range of ship types is represented by the four ships selected: a large P2-type passenger ship, a C3 and a VC2 cargo ship, and a tanker. A simultaneous comparison of the curves for the four ships reveals a number of interesting facts, the most striking of which is the remarkably good agreement between the predicted and

actual curves for all but the tanker. Being the misfit, the tanker will receive first consideration. Actually, even for this ship the general shapes of the predicted and actual curves are very similar, the main discrepancy being in the value of maximum righting arm. Time has not permitted a rigorous investigation into why this disagreement exists for the tanker when the other three ships agree so well, but there are many reasons why it can exist. Ruling out the possibility of an error in the actual curve as improbable, the discussion will be confined to possible sources of error in the method for predicting statical stability. Variation between the hull shape of the tanker and the corresponding hull shape upon which the predicted curve was based is one possibility. However, there doesn't appear to be any particular characteristic of a tanker hull that is more at variance with Taylor's Standard Series than might be the case with the passenger and cargo ships. Therefore, variation in hull shapes is not believed to be a major factor. A more likely source of error is due to the methods used in expanding the stability parameter diagram data from the basic values. As explained before, due to approximations in the method of transverse expansion, accuracy near the upper and lower limits of depth-beam ratio is probably not as good as for the basic value. Also in converting the data to draft-depth ratios in even tenths for the purpose of facilitating interpolation of the stability parameters from the diagrams, the following described approximation was used in order to conserve time. For the purpose of selecting the proper stability parameter values from the cross curves to draw the curves of statical stability of Figures XXVI to XXXVII, from which in turn data was taken to construct the stability parameter diagrams, it was necessary to know the displacement in each case corresponding to the new even-

tenth draft-depth ratio. In expanding to various longitudinal prismatic coefficients the displacement at a given draft-depth ratio is proportional to the coefficient. The approximation made was to assume that the displacement at each draft-depth ratio was proportional to the longitudinal prismatic coefficient for the basic draft-depth ratio. A spot check of the error introduced by this approximation was made by computing the displacement in this manner for the number three waterline using C_p for the number 4 waterline, and comparing this with the actual displacement from the displacement curve. The resulting error in displacement was about 3% of the correct value. Therefore, considering the possible introduction of errors due to this approximation, as well as further errors due to the method of transverse expansion, it may be seen that the farther we depart from the basic H/D value of 01625 and D/B value of 0.64 the greater the probable error in the stability parameter. For the tanker H/D = 0.775 and D/B = 0.543 which are near the upper and lower limits respectively of these ratio ranges. Thus it is possible that two errors are additive in this case.

A third and very likely source of error is due to interpolation between D/B values. There are large differences in the stability parameter between successive the D/B values used on the stability parameter diagrams. Whether or not linear interpolation between D/B values is permissible, has not been checked. Therefore this introduces another possible error.

Lastly, it will be remembered that the method of correcting C_p for deviation of the actual draft-depth ratio from the basic value of 0.625 involved an approximation. For the tanker H/D = 0.775. Therefore, the corrected C_p in this case is possibly not too close

to the value it should have.

In view of the number of possible errors in the determination of the predicted curve of statical stability it is difficult to say whether the discrepany is due to an inherent fault in the method or due to an additive accumulation of possible errors, resulting not from the basic method, but from the approximation made necessary by the limited time available to put it into a form suitable for trial. The latter thought is borne out by excellent correlation of predicted and actual results for the three ships, other than the tanker whose D/B and H/D ratios are much closer to the basic values. It must be remembered that the method as presented herein is not designed to be a finished product but only an example of a possibility. The fact that under the circumstances three out of four tries produced satisfactory results is an indication that the method has good possibilities. The results further indicates that it is unwise to spread the data from one basic form over so great a range. In this case if the data had been expanded only sufficiently to cover the passenger ship and the two cargo ships, the results would have been considered excellent throughout. Then if a new range of data were developed based on dimension ratios closer to that of the tanker, there is no reason to believe that it would not give good results for tanker-type hulls. Also it is possible to expand data more accurately than was done here. In the transverse expansion to various D/B ratios the curves of displacement in the inclined position could be made more accurate by measuring several displacements at lower waterlines. By constructing displacement curves for the hull in the upright position for each value of longitudinal prismatic coefficient, the approximation made here in interpolating for stability data at the even tenth draft-depth ratios would be avoided.

Returning now to the comparison of the predicted and actual curves of statical stability it will be seen that the predicted curves faithfully reproduce the typical characteristics of statical stability curves. For instance, the P2 curve gives the concave upward slope at the lower heel angles which is associated with high-sided ships of relatively low initial stability. It also predicts quite closely the relatively large angle of inclination at which the maximum righting arm occurs on ships of large freeboard. Turning to the tanker curves, we find the typical steep slope at the origin indicative of the large initial stability required of vessels of low freeboard. Also in this type of ship, the relatively low angle of heel at which the maximum righting arm is reached is clearly shown.

One feature characteristic of all the predicted curves is the excessive value of righting arm on the upward slope. The most likely explanation for this condition is that all of the four ships have midship section coefficients greater than the Taylor's Standard Series hulls on which the data is based. Experimenting with sketches of midship sections of hard and easy bilge curvature superimposed on each other, indicates that the shift of buoyant volume toward the low side of an inclined ship is greater for the form with easy bilge curvature, which of course corresponds with a lower midship section coefficient. Therefore it is very probable that the value of the midships section coefficient has a noticeable influence on statical stability, and that the deviation from the actual curves on the upward slopes is due to the increase in midship section coefficient of the various ships above the value for the parent Taylor's Standard Series hull.

It will be noted that the "curves" of the stability parameter

[illegible]

diagrams are all straight lines. The stability parameter points for the basic D/B ratio of 0.64 plotted so nearly in straight lines that no trend of curvature could be identified. Therefore the lines were drawn straight. For the D/B ratios of 0.52 and 0.90 there was a wider deviation of the plotted points from straight lines. However, again no recognizable trend of curvature was noticeable and the lines were drawn straight through the mean position of the various points. It is believed that the greater dispersion of points in the 0.52 and 0.90 D/B diagrams was another indication of error due to the method of expanding data to the different D/B ratios.

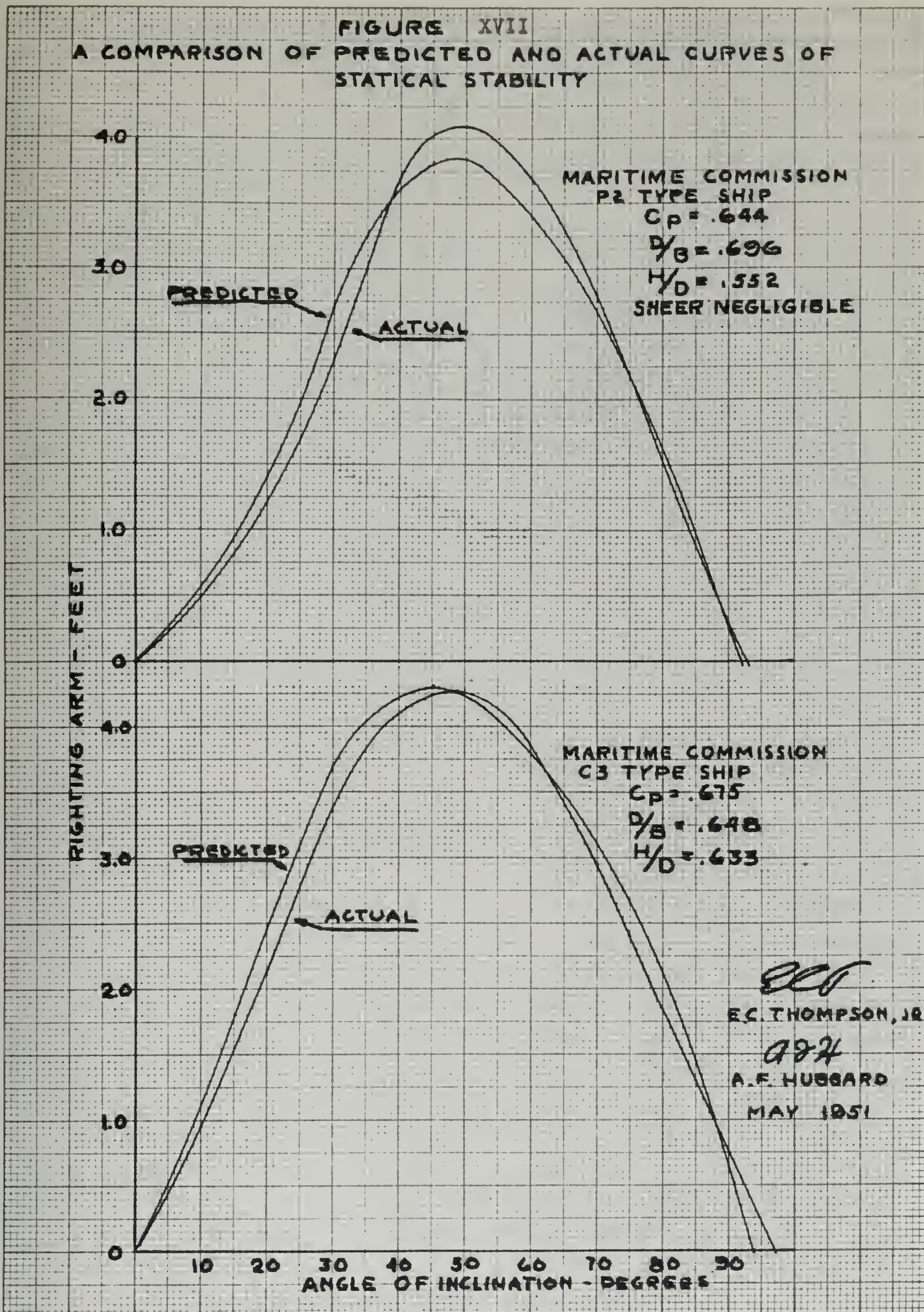


FIGURE XVII
A COMPARISON OF PREDICTED AND ACTUAL CURVES OF STATICAL STABILITY
MARITIME COMMISSION
P2 TYPE SHIP
Cp = .644
D/B = .696
H/D = .552
SHEER NEGLIGIBLE
PREDICTED
ACTUAL
MARITIME COMMISSION
C3 TYPE SHIP
Cp = .675
D/B = .648
H/D = .633
PREDICTED
ACTUAL
RIGHTING ARM - FEET
4.0
3.0
2.0
1.0
0
10 20 30 40 50 60 70 80 90
ANGLE OF INCLINATION - DEGREES
E.C. THOMPSON, JR
A.F. HUBBARD
MAY 1951

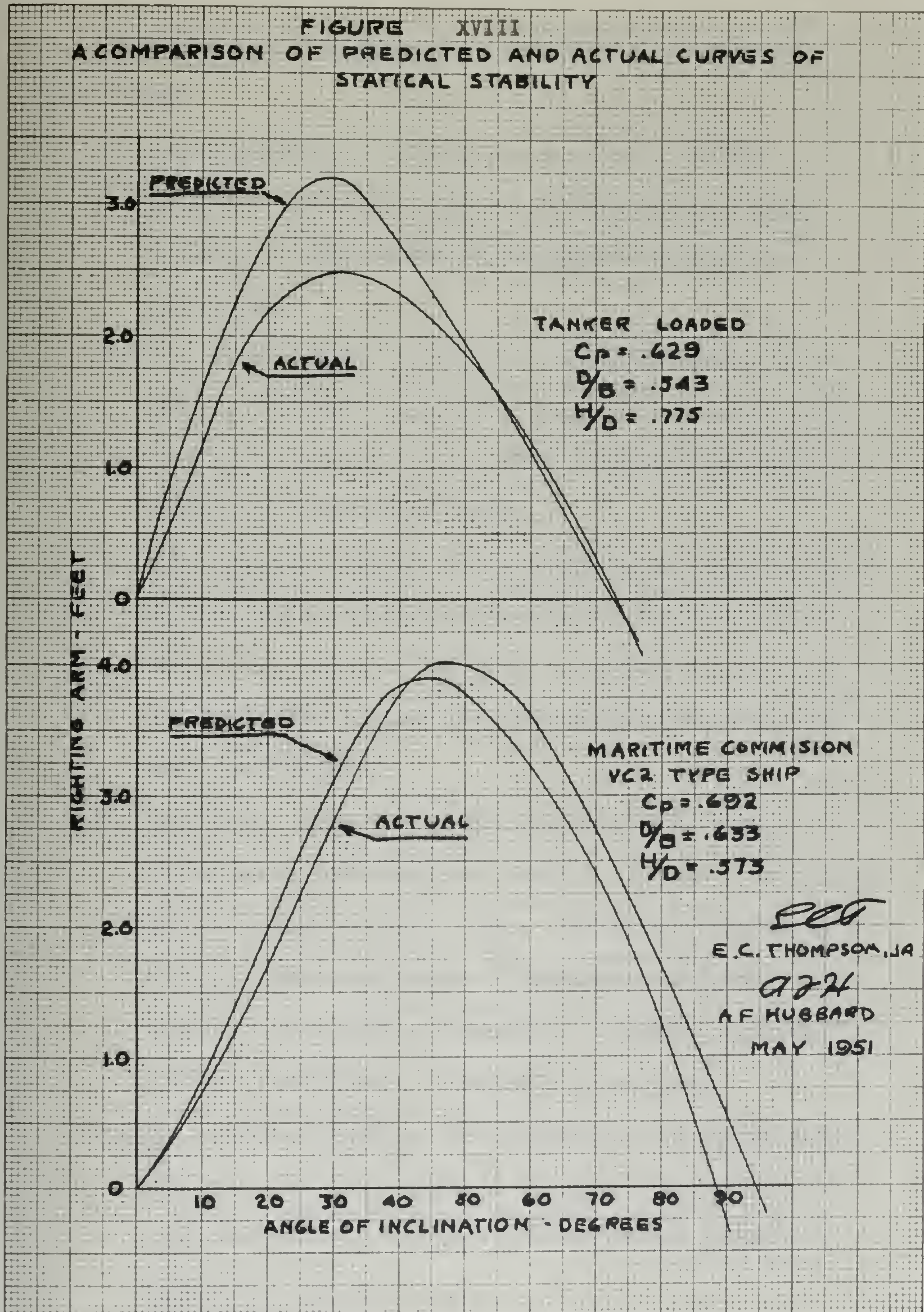


FIGURE XVIII
A COMPARISON OF PREDICTED AND ACTUAL CURVES OF STATICAL STABILITY
PREDICTED
ACTUAL
TANKER LOADED
Cp = .629
D/B = .543
H/D = .775
PREDICTED
ACTUAL
MARITIME COMMISION
VC2 TYPE SHIP
Cp = .692
D/B = .633
H/D = .573
E.C. THOMPSON, JR
A.F. HUBBARD
MAY 1951
RIGHTING ARM - FEET
3.0
2.0
1.0
0
4.0
3.0
2.0
1.0
0
10 20 30 40 50 60 70 80 90
ANGLE OF INCLINATION - DEGREES

VI CONCLUSIONS

The following conclusions are drawn from the results of this thesis:

1. It is possible to predict the statical stability characteristics of a ship in the preliminary design stage using only principal dimensions and hull coefficients.
2. The method derived herein for predicting stability is easy to use and is capable of accuracy comparable with that with which other ship characteristics may be estimated in preliminary design.
3. The statical stability characteristics of ships of normal form depend more upon principal dimensions and hull coefficients than upon the minor variations in hull form possible under a given set of principal dimensions and hull coefficients.
4. The simple ratio of righting arm divided by beam is a satisfactory dimensionless parameter for use in plotting and presenting stability data. Therefore, complications added by the introduction of metacentric height or metacentric radius into a system for predicting statical stability in preliminary design are unwarranted.
5. The effect of sheer on the righting arm at angles where the deck edge is immersed is too great to neglect even with the comparatively approximate results desired in preliminary design.
6. The procedure used herein for expanding stability data to different depth-beam ratios does not give an accuracy of results comparable with the accuracy of the basic data.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

VII RECOMMENDATIONS

In view of the results of this thesis it is believed that an improved method for predicting statical stability of ships in the preliminary design stage may be produced by basing it on the methods of this thesis as modified in the following procedure:

1. Compile one set of stability parameter diagrams for each major type of vessel desired to be included in the method. For example most passenger ships, cargo ships and tankers fall under the general classification of high midship section coefficient -- cruiser stern type of vessel which one set of diagrams should cover. A second general classification might be the lower midship section coefficient -- transom stern type of naval vessels.
2. For each major type select a basic hull form most nearly representing a mean of the range of forms included in that type. Draw the parent body plan of the hull using 10 station intervals with half spacings in the end intervals. Eliminate sheer.
3. Expand transversely the offsets of the parent body plan to give two additional depth-beam ratios above and below the basic parent form value and draw the four new body plans. This gives five body plans of different D/B ratios but each with the same C_p.
4. Integrate mechanically the five body plans for sectional areas in the upright position and for sectional areas and moments of area at 15 degree increments of inclination up to 90 degrees, using at least five different draft-depth ratios. From this the upright volumes of displacement

for the different draft-depth ratios and the basic hull stability parameter may be calculated. It will facilitate the procedure in later stages if the evenly spaced increments of draft-depth ratio to be used in the final stability parameter diagrams are used at this point in the integrating process instead of using equally spaced increments of draft as was done in this thesis.

5. Expand the stability parameter data for each D/B to cover the desired range of C_p by the method given herein. Two values of C_p above and two below the basic value should be sufficient. Note that this procedure eliminates the transverse expansion procedure used in this thesis.

6. Present the final data in a series of stability parameter diagrams similar to those derived by the present writers except plot $^{KZ}/_B$ versus D/B. This will permit interpolation between values of C_p and H/D instead of D/B and H/D. The reason for this change is that the relation between C_p and $^{KZ}/_B$ is very nearly linear and therefore lends itself readily to arithmetical interpolation.

7. To eliminate the necessity for a longitudinal prismatic coefficient correction curve, for each C_p at the basic H/D ratio compute the C_p for each other H/D ratio, and use these C_p values in the final stability parameter diagrams. Then the C_p value given on each diagram will correspond with the given H/D ratio instead of with the basic H/D ratio as in the diagrams of this thesis.

8. Retain the method given herein for sheer correction.

An alternate method of presenting the final data that would eliminate one arithmetical interpolation is as follows: Plot contours of constant H/D versus $^{KZ}/_{B}$ and D/B, giving one set of contours for each combination of θ and C_p. Then by estimating the position of a given H/D value on a line of constant D/B, a value of $^{KZ}/_{B}$ could be determined for a given C_p and θ. Doing the same for the same θ and adjacent C_p would give two values of $^{KZ}/_{B}$ for a given θ which could be interpolated between to derive the $^{KZ}/_{B}$ for the given value of C_p. This, in effect, substitutes a set of graphical interpolation for the arithmetical H/D interpolations used in the present method. It should be noted however that the proposed system has the disadvantage of requiring $^{KZ}/_{B}$ values from three times as many diagrams as for the original system.

VIII APPENDIX

A. DETAILS OF PROCEDURE

1. By tabulating principal dimensions and hull coefficients for various passenger and cargo ships, the following ranges of data were decided upon:

C_p = 0.55 to 0.80

H/D = 0.45 to 0.80

D/B = 0.52 to 0.90

2. A basic hull, using Taylor's Standard Series was selected with the following characteristics:

C_p = 0.55

B = 10.00"

L = 15.00"

D = 6.40"

H at LWL = 4.00"

The body plan for this basic hull was drawn (Figure XX).

3. Using an integrator, there were obtained areas and first moments at stations 1 through 10 for the basic hull up to waterlines: 3", 3½", 4", 4½" and 5", and at angles of heel of 0°, 15°, 30°, 45°, 60°, 75°, and 90°. The axis for moments was taken at the intersection of the baseline and the ship's centerline, point K. When it was necessary to shift the axis of moments above K to some point "G" to facilitate integration, the righting arms so determined were corrected back to the reference point "K" by adding to each KG sin θ, where θ is the angle of inclination. These data and computations were recorded on a special form made up for the purpose, for a sample of which, see Table III . A displacement curve for the basic hull was constructed using data for the upright position, (Figure XXI).

4. Using the values of KZ and their corresponding volumes of displacement computed in 3 above, cross curves of stability were plotted for the basic hull, for angles of 15°, 30°, 45°, 60°, 75° and 90°. Using volumes of displacement corresponding to H/D ratios of 0.45, 0.50, 0.60, 0.70 and 0.80, statical stability curves were drawn, (Figure XXX).

5. The next step was the expansion of the parent hull to C_p's of 0.64, 0.71 and 0.80, as illustrated in Figure XXII. This was accomplished by superimposing upon a curve of sectional areas for the hull with $C_p = 0.55$, a curve of sectional area of a hull with the new C_p. From the intersections of the original stations with the $C_p = 0.55$ curve, horizontal lines were drawn to the new C_p curve. The intersections with the new curve located a new station spacing, indicated on Figure XXII by the primed numbers.

Curves of sectional areas and moments were drawn for all the angles and all the waterlines for each new C_p, using the new station spacing to position the ordinates, and the original values of areas and moments. The areas and moments were then tabulated as read from the curves at the original ordinate spacing. Figure XXII shows the curves for only one angle of inclination and one C_p, but is illustrative of the procedure used. Data and calculations were tabulated on a special form made for the purpose, a sample of which is shown in Table VIII. Using the values of KZ as calculated in this table, cross curves and statical stability curves were drawn for the hulls with C_p's of 0.64, 0.71, and 0.80 in like manner to those drawn for the parent hull ($C_p = 0.55$), Figures XXXI to XXXIII).

6. A method of transverse expansion was now used to expand all data previously obtained for models with 10.00" beam to models with 7.12" beam and 12.30" beams, so that the final data would include a

range of D/B values from 0.52 to 0.90.

Curves of displacement in the inclined position for each C_p and each angle of heel were drawn (See Figure XXIII to XXV). From these curves, values of inclined draft were obtained for H/D ratios of 0.45, 0.50, 0.60, 0.70 and 0.80. Also using these curves and a planimeter, areas above waterlines corresponding to the foregoing H/D ratios for each curve were computed. These areas divided by corresponding displacement volume, ∇, gave P_1B_1 for each C_p, angle of heel, and value of H/D. Table IX shows a sample computation. Using these values and a scale, values of K, Z, and S, B were obtained graphically.

Figure XIX (a) and (b) shows how the basic hulls were expanded transversely. (a) represents the midship section of the parent hull, of depth D, and beam B. (b) represents the midship section of a hull whose beam has been expanded by a factor, λ, but whose other characteristics remain the same. If for the present hull, the inclined waterline $W_1' L_1'$ is drawn for the model inclined at an angle θ_1, and K_1Z_1 and P_1B_1 are known, the distance S_1B_1 can be measured.

For the expanded hull, an inclined waterline, $W_1' L_1'$, is drawn so that vertical distances $h_1 = h_2$ and $j_1 = j_2$. The distance $S_2 B_2$ is laid off so that $S_2 B_2 = (\lambda)(S_1 B_1)$, where S_2 is located by the relations $K_1 S_1 = K_2 S_2$, the proof of which is as follows.

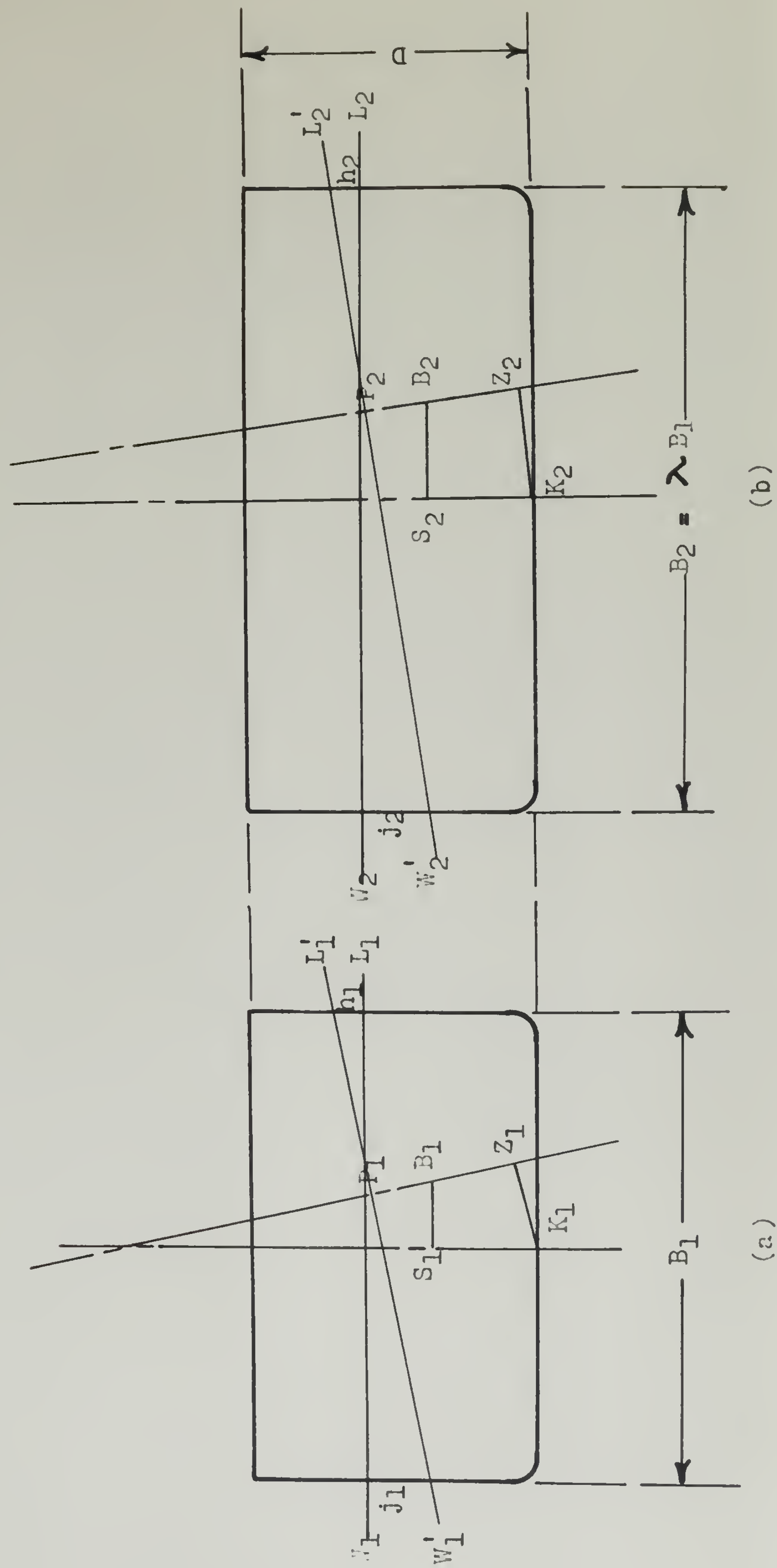
Refer to Figure XIX.

If all dimensions of ship (b) are identical with those of ship (a) except that all half breadths of (b) are increased above those of (a) by a factor λ. $(KB)_2 = (KB)_1$ by inspection. When ship (a) inclines to $W_1' L_1'$ the vertical movement FB_0 of the initial position of center of buoyancy B may be found by the principle of

Figure XIX

FIGURE XIX

GRAPHICAL METHOD OF TRANSVERSE EXPANSION



moment transfer as follows:

$$BB_1 \times \nabla_1 = v_{i_1} \times \frac{j_1}{3} - v_{e_1} \frac{h_1}{3}$$

where BB_1 = movement of B parallel to ships

∇_1 = ship vol. of displacement

v_{i_1} = volume of immersed wedge

v_{e_1} = volume of emerged wedge

j_1 & h_1 = as shown on the diagram

$$K_1S_1 = (KB)_1 + BB_1 = (KB)_1 + \left[\frac{v_{i_1} \times \frac{j_1}{3} + v_{e_1} \frac{h_1}{3}}{\nabla_1}\right]$$

But also $BB_2 \times \nabla_2 = v_{i_2} \times \frac{j_2}{3} + v_{e_2} \frac{h_2}{3}$

and $\nabla_2 = \lambda \nabla_1$, $v_{i_2} = \lambda v_{i_1}$, $v_{e_2} = \lambda v_{e_1}$

$j_2 = j_1$, $h_2 = h$, $K_2B = K_1B$

$$K_2S_2 = (KB)_1 + \left[\frac{\lambda v_{i_1} \times \frac{j_1}{3} + \lambda v_{e_1} \frac{h_1}{3}}{\lambda \nabla_1}\right] = K_1S_1$$

A perpendicular to $W_2{}^1L_2{}^1$ drawn through B_2 locates Z_2, and distance K_2Z_2 can be measured. This distance K_2Z_2 is the righting arm for an inclination of θ_2 of the expanded hull. The value of θ_2 may be obtained graphically by means of a protractor, or analytically by means of the relation: $\tan \theta_2 = \frac{1}{\lambda} \tan \theta_1$. This accounts for the odd angles of inclination found on the cross curves for B = 7.12" & 12.30".

In the application of this method used to obtain data for beams of 7.12" and 12.30", S_2B_2, and ∇_2, and S_3B_3 and ∇_3 were obtained by multiplying S_1B_1 and ∇_1 by λ_2 and λ_3 respectively, where $\lambda_2 = B_2/B_1$ and $\lambda_3 = B_3/B_1$. Values of K_2Z_2 and θ_2 were obtained by rotating $W_1{}^1L_1{}^1$ an amount so as to keep $h_1 = h_2$ and $j_1 = j_2$. This was repeated to obtain values of K_3Z_3 and θ_3. The results were tabulated in Tables X to XIII .

Cross curves and statical stability curves were drawn for the values of KZ thus obtained (Figures XXVI to XXXVII).

7. Figures XXVI to XXXVII show the cross curves and statical stability curves for the twelve hulls obtained from the parent hull by three longitudinal expansions and two transverse expansions. From these twelve sets of curves, twelve tables (Tables XIV to XXV) were made up, listing values of KZ and KZ/B for each C_p and each beam.

8. Based on the tables referred to above, fifteen Righting Arm Parameter Diagrams were made up (Figures II to XVI). These diagrams of GZ/B versus C_p for constant increments ~~moments~~ of θ are for values of D/B ranging from 0.45 to 0.80 and D/B varying from 0.52 to 0.90. The C_p range is from 0.55 to 0.80 and θ from 0° to 90°.

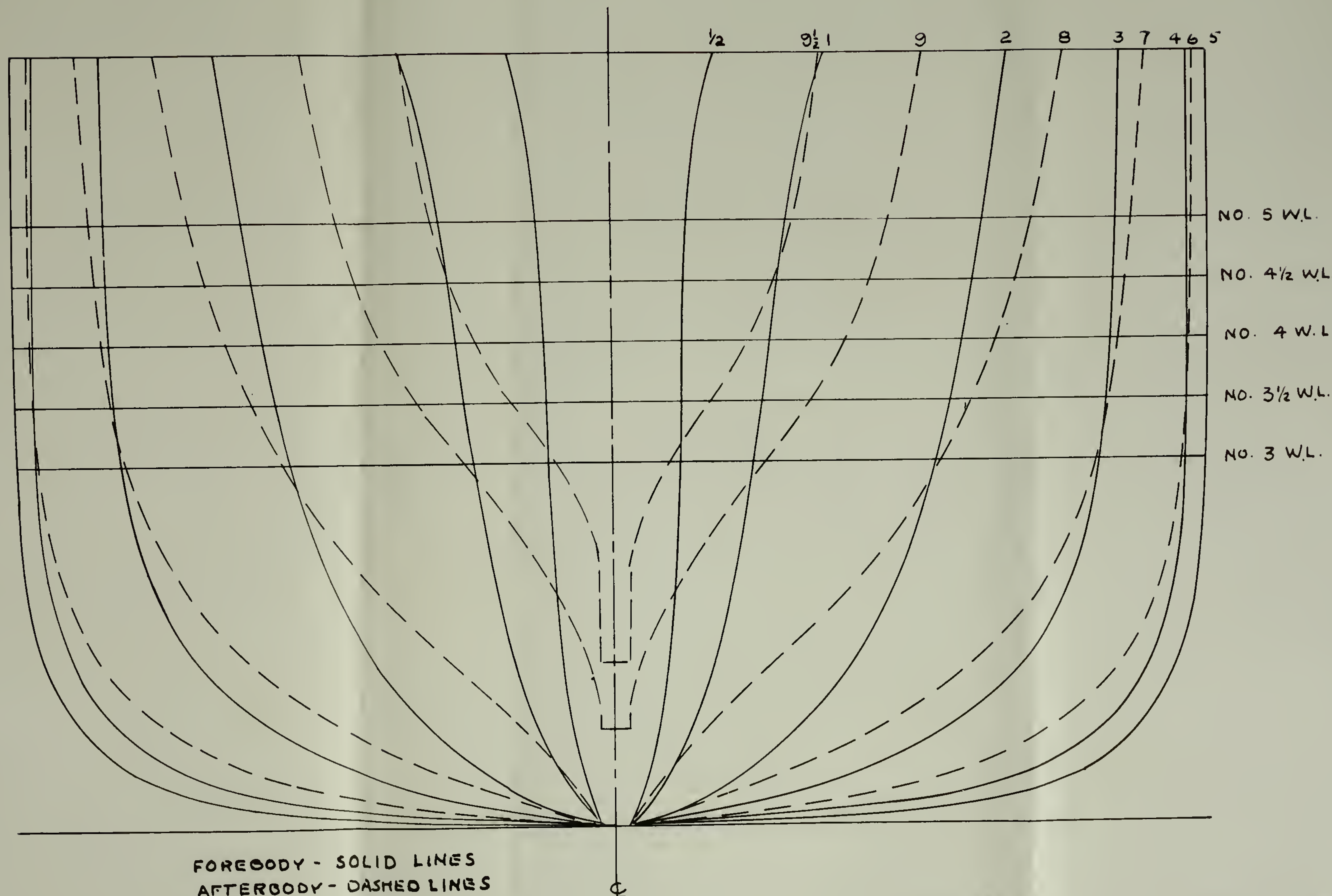
9. A corrective curve (Figure I) was made up to be applied to C_p before entering in the Righting Arm Parameter Diagrams. This curve was made up by computing values of C_p for H/D values within the range covered in the parameter diagrams, by dividing volume of displacement to a given waterline by the product of length times the midship section area to that given waterline. The ratio of C_p at the 4" waterline to the C_p computed as above for some other waterline gives the correction factor.

10. A form was made for use with the parameter diagrams referred to ~~above~~ in "9" above. A sample computation using this form is shown in Table II . Calculations using this form and the parameter diagrams were performed for four different ships. The results of these calculations were statical stability curves. These curves were plotted and compared with those included in the ships' plans and computed by conventional methods. Figures XVII and ~~to~~ XVIII show a comparison of the statical stability curves obtained by the two methods: e.g. that based on the parameter diagrams of this thesis and by the conventional method.

B. DATA AND CALCULATIONS

FIGURE XX

BODY PLAN - TAYLOR'S STANDARD SERIES



FOREBODY - SOLID LINES
AFTERBODY - DASHED LINES

PARENT FORM INTEGRATED FOR BASIC DATA

BEAM 10" DEPTH 6.4" FULL SCALE

LENGTH FOR STABILITY DATA 15"

PRISMATIC COEFFICIENT 0.55

E.C.THOMPSON, JR. A.F HUBBARD

MAY 1951

Figure XXI

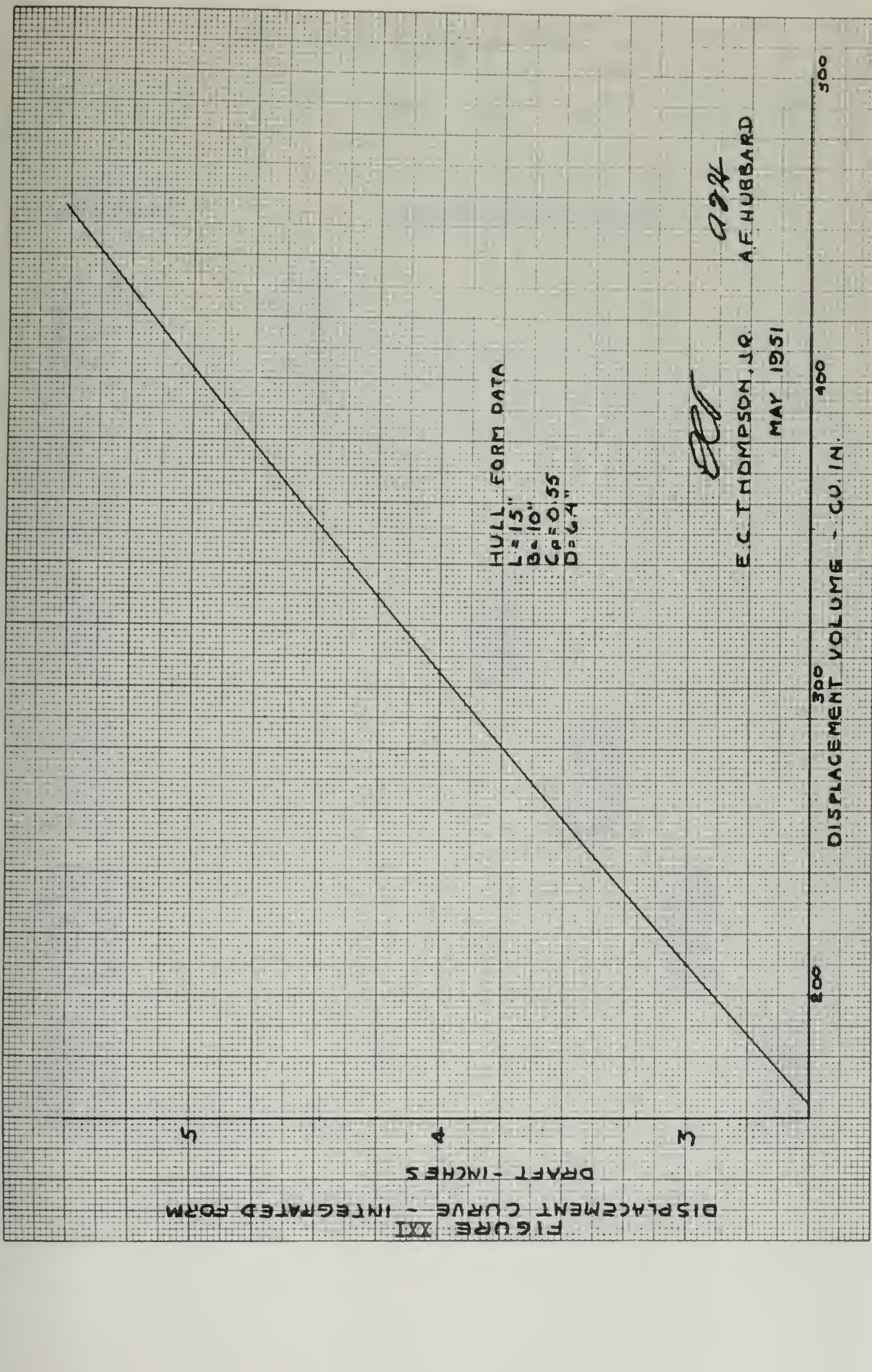


FIGURE XXI
DISPLACEMENT CURVE - INTEGRATED FORM
DRAFT - INCHES
3
4
5
DISPLACEMENT VOLUME - CU. IN.
200
300
400
500
HULL FORM DATA
L=15"
B=10"
Cp=0.55
D=6.4"
E.C. THOMPSON, JR.
A.E. HUBBARD
MAY 1951

TABLE IV

DATA FOR CROSS CURVES $C_p = 0.55$

Angle of Heel	15°	30°	45°	60°	75°	90°
Volume of Displacement	Righting Arm in Inches					
217.92	1.10					
265.71	1.10					
315.52	1.11					
366.48	1.13					
419.22	1.16					
208.47		2.23				
258.72		2.21				
310.91		2.22				
361.37		2.19				
408.14		2.15				
224.24			3.15			
271.45			3.09			
326.70			2.96			
364.15			2.94			
405.42			2.86			
273.21				3.53		
316.59				3.50		
356.37				3.44		
397.60				3.35		
449.77				3.20		
238.86					3.91	
288.88					3.74	
329.04					3.68	
367.31					3.64	
403.52					3.59	
255.08						3.64
298.40						3.59
339.71						3.57
377.52						3.57
410.94						3.57

TABLE V

DATA FOR CROSS CURVES $C_p = 0.64$

Angle of Heel	15°	30°	45°	60°	75°	90°
Volume Of Displacement	Righting Arm in Inches					
260	1.09					
307	1.13					
343	1.20					
423	1.13					
474	1.17					
245		2.25				
298		2.27				
357		2.26				
413		2.20				
463		2.15				
261			3.22			
311			3.15			
362			3.05			
413			2.94			
458			2.85			
244				3.73		
292				3.61		
401				3.43		
444				3.33		
480				3.29		
237					3.85	
278					3.81	
366					3.71	
408					3.61	
446					3.57	
248						3.64
333						3.54
379						3.51
416						3.52
455						3.50

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE VI

DATA FOR CROSS CURVES $C_p = 0.71$

Angle of Heel	15°	30°	45°	60°	75°	90°
Volume of Displacement	Righting Arm in Inches					
284	1.15					
361	1.09					
403	1.15					
464	1.23					
525	1.17					
272		2.34				
336		2.28				
395		2.28				
456		2.21				
507		2.15				
290			3.27			
344			3.18			
396			3.08			
451			2.94			
498			2.84			
272				3.76		
323				3.67		
435				3.44		
482				3.32		
520				3.19		
263					3.89	
308					3.80	
396					3.67	
442					3.57	
480					3.55	
279						3.58
364						3.49
407						3.48
450						3.45
488						3.46

[illegible]

TABLE VII

DATA FOR CROSS CURVES $C_p = 0.80$

Angle of Heel	15°	30°	45°	60°	75°	90°
Volume of Displacement	Righting Arm in Inches					
326	1.18					
389	1.16					
454	1.17					
505	1.19					
538	1.28					
310		2.44				
378		2.35				
444		2.31				
509		2.24				
567		2.14				
330			3.32			
389			3.23			
445			3.10			
500			2.97			
552			2.64			
310				3.78		
365				3.64		
478				3.44		
527				3.33		
570				3.25		
300					3.85	
346					3.79	
436					3.64	
482					3.57	
527					3.51	
313						3.55
398						3.46
445						3.41
487						3.41
529						3.41

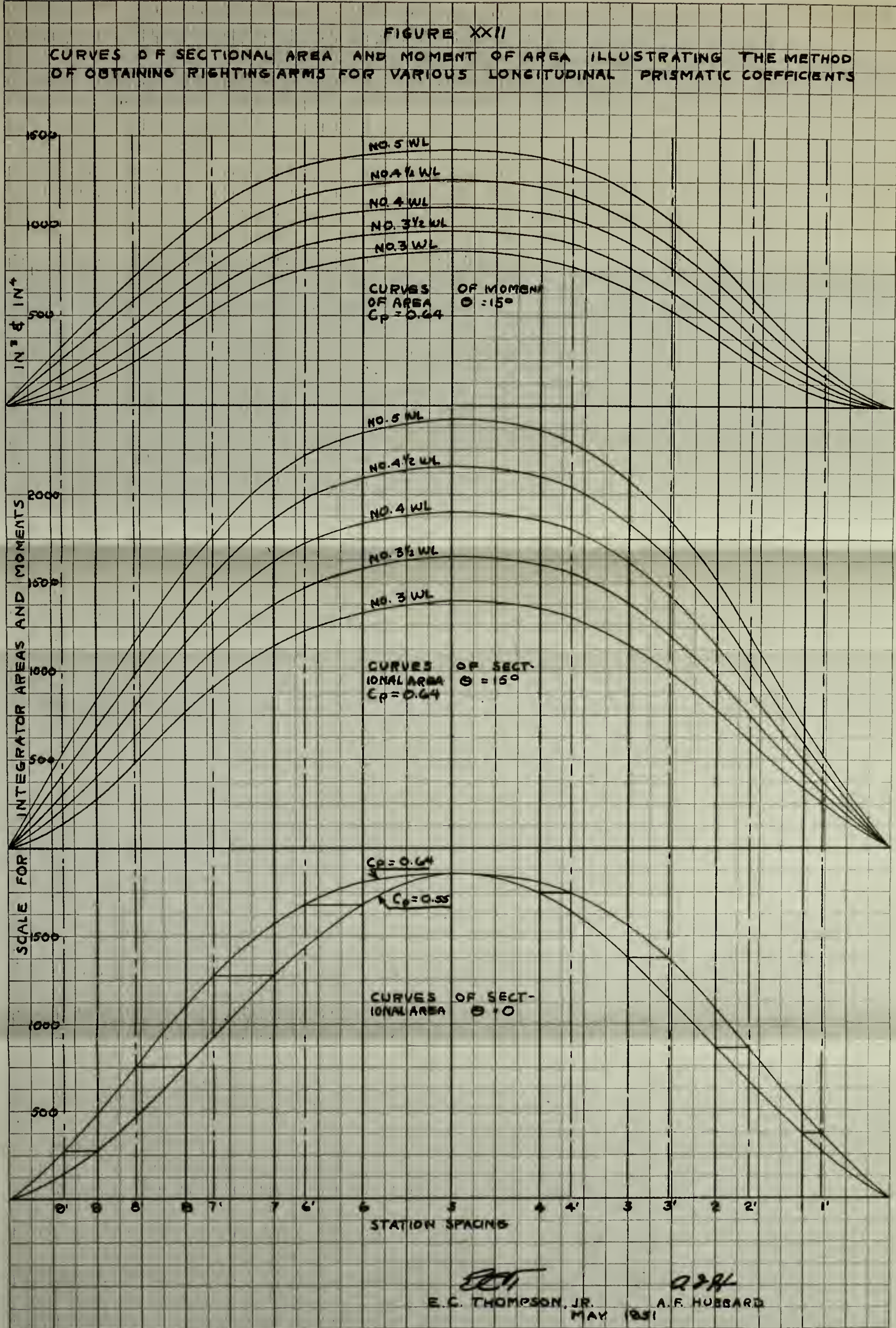


FIGURE XXII
CURVES OF SECTIONAL AREA AND MOMENT OF AREA ILLUSTRATING THE METHOD OF OBTAINING RIGHTING ARMS FOR VARIOUS LONGITUDINAL PRISMATIC COEFFICIENTS
NO. 5 WL
NO. 4½ WL
NO. 4 WL
NO. 3½ WL
NO. 3 WL
CURVES OF MOMENT OF AREA θ = 15° Cp = 0.64
IN³ & IN⁴
1500
1000
500
2000
CURVES OF SECTIONAL AREA θ = 15° Cp = 0.64
SCALE FOR INTEGRATOR AREAS AND MOMENTS
Cp = 0.64
Cp = 0.55
CURVES OF SECTIONAL AREA θ = 0
9' 9 8 8' 7' 7 6' 6 5 4 4' 3 3' 2 2' 1'
STATION SPACING
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951

Figure XXII

TABLE VIII

SAMPLE COMPUTATION — CALCULATION FOR LONGITUDINAL EXPANSION

HULL NO. 64	HULL NO. 71	HULL NO. 80

Length for displacement 15" B 10" G is taken ~~at K~~ 1 " above K

Inclination 0° 15° 30° 45° 60° 75° 90° s = 1.5" = 1/4 WL 3 3½ 4 4½ 5 " above K

H/B = 0.45 D/B = 0.64 H/D = 0.703

Sta	AREA (C_p = 0.64)	MOMENT	Sta	AREA (C_p = 0.71)	MOMENT	Sta	AREA (C_p = 0.80)	MOMENT
1	810	920	1	1020	1190	1	1450	1700
3	1870	2260	3	1990	2410	3	2070	2520
5	2100	2510	5	2110	2560	5	2100	2560
7	1870	2250	7	1990	2480	7	2070	2550
9	980	1230	9	1220	1470	9	1530	1860
Σ_1	7630	9320	Σ_1	8330	10110	Σ_1	9220	11190
$2\Sigma_1$	15260	18540	$2\Sigma_1$	17660	20220	$2\Sigma_1$	18440	22380
2	1470	1720	2	1680	1980	2	1940	2330
4	2070	2500	4	2100	2540	4	2100	2560
6	2050	2530	6	2080	2560	6	2100	2560
8	1530	1890	8	1730	2150	8	1950	2430
Σ_2	7120	8640	Σ_2	7590	9230	Σ_2	8090	9880
Σ	22380	27280	Σ	24250	29450	Σ	26530	32260

Hull No. 64

Vol. of Δ = (Σ area)(Area const.)([illegible])
= (22380)(.01986)
= 444.47

Vol. Moment = (Σ mom.)(Mom. const.)([illegible])
= (27280)(.04003)
= 1092.02

Corr. GZ = $\frac{\text{Vol. Mom.}}{\text{Vol. of }\Delta} = \frac{(1092.02)}{(444.47)} = 2.46$

GZ for KG = 0; 2.46 + 0.87 = 3.33

$\frac{KZ}{B} = \left(\frac{1}{10}\right)$(GZ for KG = 0) = 0.333

Hull No. 71

Vol. of Δ = (Σ area)(Area const.)([illegible])
= (24250)(.01986)
= 481.61

Vol. Moment = (Σ mom.)(Mom. const.)([illegible])
= (29450)(.04003)
= 1178.88

Corr. GZ = $\frac{\text{Vol. Mom.}}{\text{Vol. of }\Delta} = \frac{(1178.88)}{(481.61)} = 2.45$

GZ for KG = 0; 2.45 + 0.87 = 3.32

$\frac{KZ}{B} = \left(\frac{1}{10}\right)$(GZ for KG = 0) = 0.332

Hull No. 80

Vol. of Δ = (Σ area)(Area const.)([illegible])
= (26530)(.01986)
= 526.89

Vol. Moment = (Σ mom.)(Mom. const.)([illegible])
= (32260)(.04003)
= 1291.37

Corr. GZ = $\frac{\text{Vol. Mom.}}{\text{Vol. of }\Delta} = \frac{(1291.37)}{(526.89)} = 2.45$

GZ for KG = 0; 2.45 + 0.87 = 3.32

$\frac{KZ}{B} = \left(\frac{1}{10}\right)$(GZ for KG = 0) = 0.332

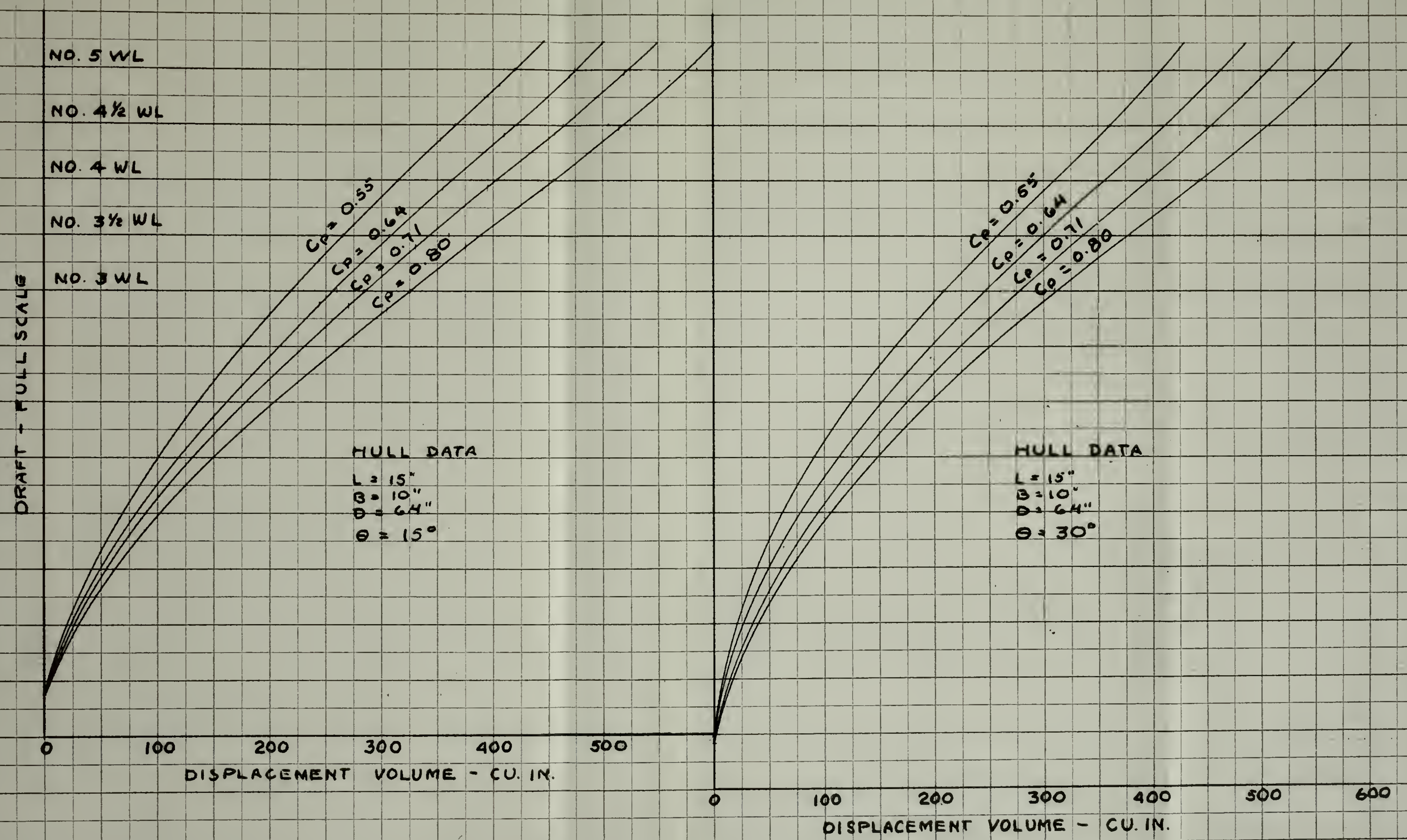
19 March, 1951

E. C. Thompson, Jr
A. F. Hubbard

Figure VIII

FIGURE XXIII

CURVES OF DISPLACEMENT IN THE INCLINED POSITION FOR USE IN TRANSVERSE EXPANSION OF THE PARENT FORMS



E.C. THOMPSON, JR. A.F. HUBBARD

MAY 1931

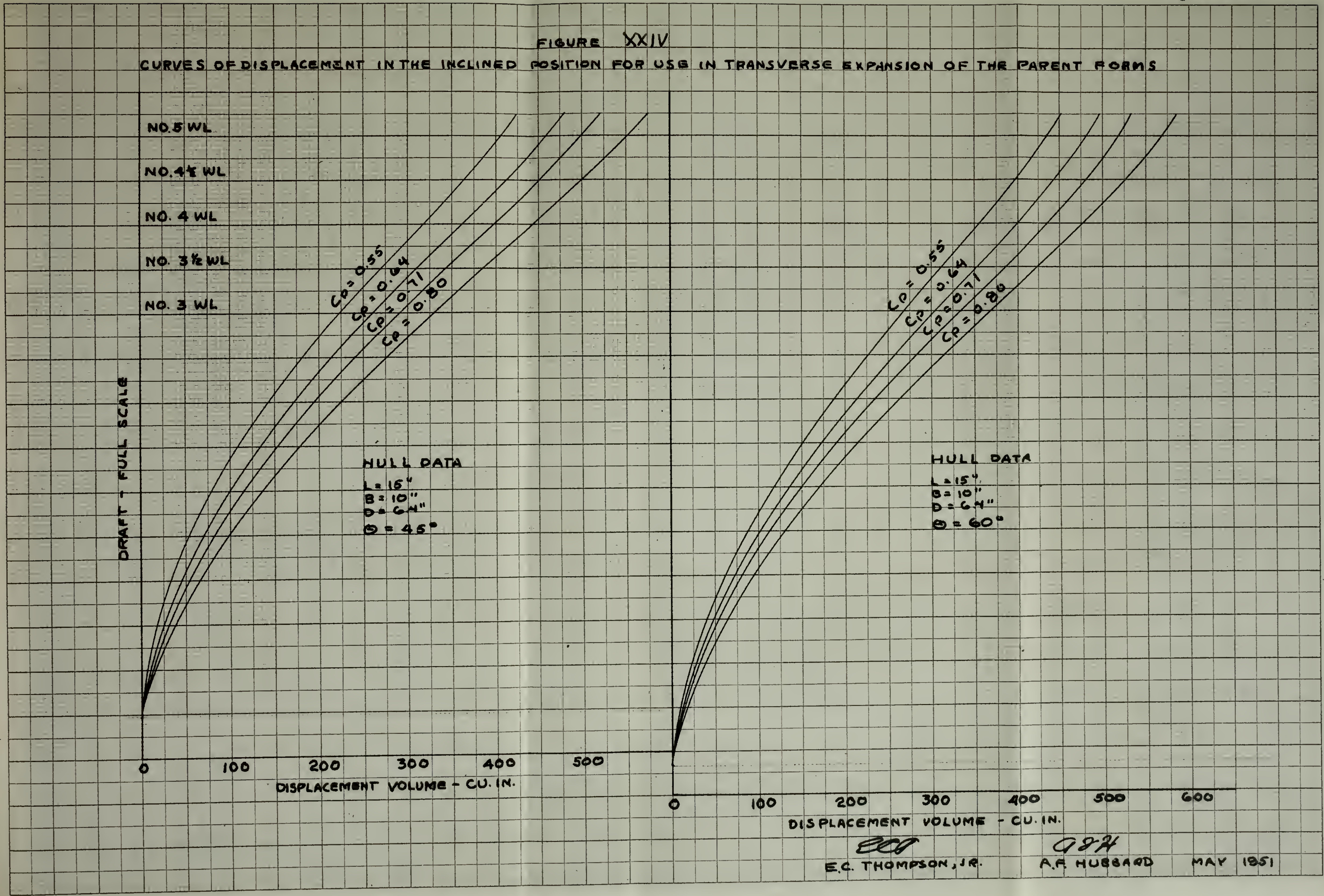


FIGURE XXIV
CURVES OF DISPLACEMENT IN THE INCLINED POSITION FOR USE IN TRANSVERSE EXPANSION OF THE PARENT FORMS
NO. 5 WL
NO. 4½ WL
NO. 4 WL
NO. 3½ WL
NO. 3 WL
DRAFT - FULL SCALE
CP = 0.55
CP = 0.64
CP = 0.71
CP = 0.80
HULL DATA
L = 15"
B = 10"
D = 6.4"
Θ = 45°
0
100
200
300
400
500
DISPLACEMENT VOLUME - CU. IN.
CP = 0.55
CP = 0.64
CP = 0.71
CP = 0.80
HULL DATA
L = 15"
B = 10"
D = 6.4"
Θ = 60°
0
100
200
300
400
500
600
DISPLACEMENT VOLUME - CU. IN.
E.C. THOMPSON, JR.
A.F. HUBBARD
MAY 1951

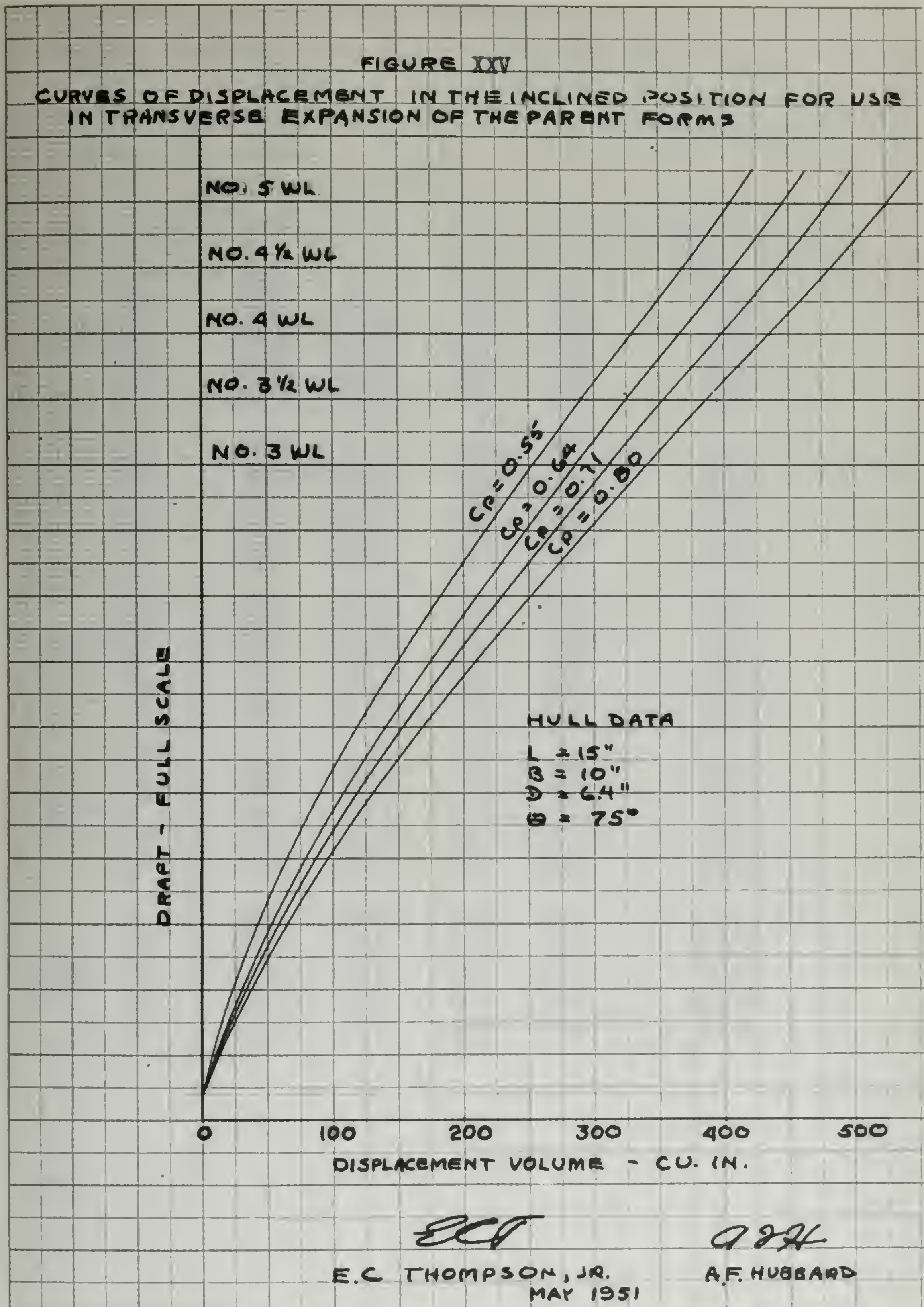


FIGURE XXV
CURVES OF DISPLACEMENT IN THE INCLINED POSITION FOR USE IN TRANSVERSE EXPANSION OF THE PARENT FORMS
NO. 5 WL
NO. 4½ WL
NO. 4 WL
NO. 3½ WL
NO. 3 WL
CP = 0.55
CP = 0.64
CP = 0.71
CP = 0.80
HULL DATA
L = 15"
B = 10"
D = 6.4"
θ = 75°
DRAFT - FULL SCALE
0
100
200
300
400
500
DISPLACEMENT VOLUME - CU. IN.
E.C. THOMPSON, JR.
MAY 1951
A.F. HUBBARD

TABLE IX

SAMPLE COMPUTATION

COMPUTATION OF P_1B_1 FROM CURVES OF INCLINED DISPLACEMENT

Length for Displacement 15" $B = 10"$ Area Constant $= 2.00$

$C_p = 0.55$

θ	To WL	Start	Finish	Diff.	Vol.	$(2)\frac{Diff.}{Vol.} = P_1B_1$
	3"	1814	1979	165	218	1.51
	3½	2624	2845	221	265	1.67
15°	4	4786	5083	297	315	1.89
	4½	6407	6785	378	367	2.06
	5	8283	8762	479	420	2.28
	3	3054	3206	152	209	1.45
	3½	3858	4064	206	258	1.60
30°	4	4950	5224	274	310	1.77
	4½	6386	6748	362	360	2.01
	5	8221	8683	462	409	2.26
	3	1870	2050	180	223	1.61
	3½	2844	3090	246	271	1.82
45°	4	5700	6017	317	319	1.99
	4½	5751	6157	406	364	2.23
	5	7785	8285	500	405	2.47
	3	2145	2405	260	267	1.95
	3½	3407	3737	330	311	2.12
60°	4	5011	5425	414	356	2.33
	4½	7004	7508	504	398	2.53
	5	2411	3025	614	436	2.82
	3	8127	8382	255	252	2.02
	3½	9361	9682	321	285	2.25
75°	4	0918	1317	399	328	2.43
	4½	2847	3337	490	367	2.67
	5	5177	5762	585	404	2.90

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	

Table X

TABLE X

D = 6.4"			TRANSVERSE EXPANSION DATA												C_p = 0.55	
							λ_2 = 0.712; B_2 = 7.12				λ_3 = 1.230; B_3 = 12.3					
θ_1	$\frac{H}{D}$	∇_1	Inc. Draft	K_1Z_1	P_1B_1	S_1B_1	S_2B_2	θ_2	∇_2	K_2Z_2	S_3B_3	θ_3	∇_3	K_3Z_3		
	0.468	210	3.54	1.09	1.47	0.69	0.49		150	1.03	0.85		258	1.17		
	0.547	257	4.05	1.10	1.65	0.62	0.44		183	1.11	0.76		316	1.17		
15°	0.625	306	4.55	1.11	1.84	0.53	0.38	20.7	218	1.15	0.65	12.3	376	1.12		
	0.703	353	5.00	1.12	2.02	0.48	0.34		251	1.21	0.59		434	1.12		
	0.781	403	5.50	1.15	2.22	0.44	0.31		287	1.29	0.54		496	1.13		
	0.468	210	4.09	2.23	1.45	1.25	0.89		150	1.89	1.54		258	2.20		
	0.547	257	4.58	2.22	1.59	1.24	0.88		183	2.13	1.53		316	2.39		
30°	0.625	306	5.06	2.22	1.77	1.08	0.77	39.1	218	2.20	1.33	24.9	376	2.32		
	0.703	353	5.53	2.20	1.98	0.91	0.65		251	2.27	1.12		434	2.21		
	0.781	403	6.06	2.16	2.23	0.72	0.51		287	2.28	0.89		496	2.08		
	0.468	210	4.39	3.17	1.56	2.06	1.47		150	2.82	2.53		258	3.49		
	0.547	257	4.88	3.11	1.73	1.78	1.27		183	2.86	2.19		316	3.35		
45°	0.625	306	5.39	3.04	1.94	1.52	1.08	54.6	218	2.89	1.87	39.1	376	3.19		
	0.703	353	5.93	2.96	2.17	1.25	0.89		251	2.91	1.54		434	3.07		
	0.781	403	6.53	2.86	2.46	0.93	0.66		287	2.91	1.14		496	2.84		
	0.468	210	4.48	3.67	1.76	2.46	1.75		150	3.24	3.02		258	4.02		
	0.547	257	5.02	3.59	1.91	2.08	1.48		183	3.27	2.56		316	3.87		
60°	0.625	306	5.60	3.52	2.09	1.71	1.22	67.7	218	3.32	2.10	54.6	376	3.73		
	0.703	353	6.16	3.44	2.30	1.37	0.98		251	3.33	1.68		434	3.59		
	0.581	403	6.78	3.34	2.58	1.01	0.72		287	3.31	1.24		496	3.40		
	0.468	210	4.21	3.87	1.84	280	1.99		150	3.57	3.44		258	4.17		
	0.547	257	4.82	3.79	2.08	2.43	1.73		183	3.54	2.99		316	4.06		
75°	0.625	306	5.51	3.71	2.33	1.99	1.42	79.2	218	3.51	2.45	71.7	376	3.82		
	0.703	353	6.13	3.64	2.57	1.56	1.11		251	3.46	1.92		434	3.76		
	0.781	463	6.80	3.59	2.89	1.23	0.88		287	3.43	1.51		496	3.70		

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TABLE XI

$D = 6.4"$			TRANVERSE EXPANSION DATA											$C_D = 0.64$
							$\lambda_2 = 0.712$; $B_2 = 7.12$				$\lambda_3 = 1.230$; $B_3 = 12.30$			
θ_1	$\frac{H}{D}$	∇_1	Inc. Draft	K_1Z_1	P_1B_1	S_1B_1	S_2B_2	θ_2	∇_2	K_2Z_2	S_3B_3	θ_3	∇_3	K_3Z_3
	0.468	244	3.52	1.11	1.45	0.70	0.50		174	1.04	0.86		300	1.18
	0.547	299	4.05	1.12	1.68	0.65	0.46		213	1.10	0.80		368	1.18
15°	0.625	356	4.57	1.14	1.90	0.59	0.42	20.7°	253	1.17	0.73	12.3°	438	1.18
	0.703	411	5.04	1.16	2.09	0.53	0.38		292	1.23	0.65		505	1.28
	0.781	469	5.57	1.18	2.31	0.47	0.33		334	1.29	0.58		577	1.16
	0.468	244	4.08	2.26	1.49	1.47	1.05		174	1.98	1.81		300	2.41
	0.547	299	4.59	2.27	1.71	1.32	0.94		213	2.13	1.62		368	2.45
30°	0.625	356	5.09	2.26	1.92	1.20	0.85	39.1°	253	2.20	1.48	24.9°	438	2.40
	0.703	411	5.58	2.18	2.11	0.93	0.66		292	2.15	1.14		505	2.17
	0.781	469	6.18	2.12	2.37	0.75	0.53		334	2.29	0.92		577	2.09
	0.468	244	4.36	3.24	1.69	2.24	1.60		174	2.85	2.76		300	3.62
	0.547	299	4.93	3.16	1.87	1.88	1.34		213	2.87	2.31		368	3.42
45°	0.625	356	5.47	3.07	2.06	1.57	1.12	54.6°	253	2.88	1.93	39.1°	438	3.23
	0.703	411	6.01	2.97	2.28	1.29	0.92		292	2.90	1.59		505	3.08
	0.781	469	6.67	2.82	2.64	0.94	0.67		334	2.84	1.16		577	2.82
	0.468	244	4.53	3.73	1.75	2.46	1.75		174	3.37	3.02		300	4.09
	0.547	399	5.13	3.61	1.95	2.06	1.47		213	3.34	2.54		368	3.93
60°	0.625	356	5.70	3.50	2.17	1.68	1.20	67.7°	253	3.32	2.07	54.6°	438	3.73
	0.703	411	6.30	3.39	2.43	1.32	0.94		292	3.28	1.62		505	3.51
	0.781	469	7.02	3.30	2.80	1.00	0.71		334	3.28	1.23		577	3.38
	0.468	244	4.29	3.84	1.78	9.67	1.90		174	3.57	3.28		300	4.12
	0.547	299	5.00	3.79	2.15	2.31	1.65		213	3.53	2.84		368	4.01
75°	0.625	356	5.68	3.73	2.51	2.00	1.42	79.2°	253	3.53	2.46	71.7°	438	3.92
	0.703	411	6.35	3.64	2.80	1.60	1.14		292	3.48	1.97		505	3.78
	0.781	469	7.16	3.52	3.13	1.12	0.80		334	3.43	1.38		577	3.60

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TABLE XII

$D = 6.4''$			TRANVERSE EXPANSION DATA								$C_D = 0.71$			
							$\lambda_2 = 0.712$; $B_2 = 7.12$				$\lambda_3 = 1.230$; $B_3 = 12.30$			
θ_1	$\frac{H}{D}$	∇_1	Inc. Draft	K_1Z_1	P_1B_1	S_1B_1	S_2B_2	θ_2	∇_2	K_2Z_2	S_3B_3	θ_3	∇_3	K_3Z_3
	0.468	271	3.50	1.15	1.44	0.75	0.53		193	1.07	0.92		333	1.22
	0.547	332	4.03	1.15	1.66	0.66	0.47		236	1.13	0.81		408	1.21
15°	0.625	395	4.58	1.16	1.88	0.59	0.42	20.7°	281	1.18	0.73	12.3°	486	1.18
	0.703	456	5.07	1.16	2.09	0.53	0.38		324	1.24	0.65		561	1.17
	0.781	520	5.60	1.17	2.35	0.42	0.30		370	1.29	0.52		640	1.12
	0.468	271	4.03	2.33	1.55	1.59	1.13		193	2.10	1.96		333	2.60
	0.547	332	4.54	231	1.74	1.42	1.01		236	2.16	1.75		408	2.52
30°	0.625	395	5.09	2.28	1.93	1.19	0.85	39.1°	281	2.22	1.46	24.9°	486	2.39
	0.703	456	5.59	2.22	2.15	1.02	0.73		324	2.28	1.26		561	2.30
	0.781	520	6.23	2.13	2.47	0.76	0.54		370	2.28	0.94		640	2.10
	0.468	271	4.31	3.30	1.70	2.30	1.64		193	2.81	2.83		333	3.67
	0.547	332	4.91	3.20	1.93	1.97	1.40		236	2.88	2.42		408	3.48
45°	0.625	395	5.50	3.09	2.17	1.64	1.17	54.6°	281	2.90	2.02	39.1°	486	3.28
	0.703	456	6.07	2.95	2.91	1.67	1.19		324	2.72	2.06		561	3.08
	0.781	520	7.20	3.18	2.99	0.92	0.67		370	3.19	1.13		640	3.22
	0.468	271	4.53	3.76	1.78	2.48	1.77		193	3.38	3.05		333	4.13
	0.547	332	5.14	3.65	1.98	2.06	1.47		236	3.33	2.54		408	3.92
60°	0.625	395	5.78	3.53	2.21	1.67	1.19	67.7°	281	3.34	2.05	54.6°	486	3.71
	0.703	456	6.38	3.39	2.99	1.74	1.24		324	3.17	2.15		561	3.62
	0.781	520	7.20	3.18	2.99	0.92	0.67		370	3.19	1.13		640	3.22
	0.468	271	4.30	3.87	1.83	2.72	1.94		193	3.57	3.35		333	4.14
	0.547	332	5.30	3.77	2.20	2.33	1.66		236	3.53	2.86		408	4.02
75°	0.625	395	5.79	3.67	2.54	1.89	1.35	79.2°	281	3.48	2.32	71.7°	486	3.73
	0.703	456	6.49	3.57	2.87	1.53	1.09		324	3.42	1.88		561	3.70
	0.781	520	7.40	3.55	3.25	1.00	0.71		370	3.35	1.23		640	3.49

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TAble XIII

TABLE XIII

D = 6.4" TRANVERSE EXPANSION DATA $C_p = 0.80$

							$\lambda_2 = 0.712$; $B_2 = 7.12$				$\lambda_3 = 1.230$; $B_3 = 12.30$			
θ_1	$\frac{H}{D}$	∇_1	Inc. Draft	K_1Z_1	P_1B_1	S_1B_1	S_2B_2	θ_2	∇_2	K_2Z_2	S_3B_3	θ_3	∇_3	K_3Z_3
	0.468	306	3.47	1.18	1.42	0.78	0.56		218	1.02	0.96		377	1.29
	0.547	374	4.03	1.17	1.66	0.68	0.48		266	1.04	0.84		460	1.24
15°	0.625	445	4.56	1.16	1.88	0.61	0.43	20.7°	317	1.18	0.75	12.3°	547	1.20
	0.703	514	5.11	1.19	2.14	0.56	0.40		366	1.26	0.69		632	1.21
	0.781	586	5.72	1.23	2.46	0.54	0.38		417	1.34	0.67		721	1.23
	0.468	306	4.03	2.44	1.58	1.69	1.20		218	2.16	2.08		377	2.72
	0.547	374	4.58	3.25	1.75	1.42	1.01		266	2.21	1.75		460	2.53
30°	0.625	445	5.10	2.31	1.95	1.19	0.85	39.1°	317	2.22	1.46	24.9°	547	2.38
	0.703	514	5.67	2.23	2.20	1.01	0.72		366	2.29	1.24		632	2.31
	0.781	586	6.34	2.09	2.57	0.74	0.53		417	2.26	0.91		721	2.97
	0.468	306	4.30	3.33	1.80	2.40	1.71		218	2.87	2.95		377	3.74
	0.547	374	4.93	3.26	1.98	2.03	1.45		266	2.93	2.50		460	3.56
45°	0.625	445	5.54	3.10	2.22	1.64	1.17	54.6°	317	2.88	2.02	39.1°	547	3.28
	0.703	514	6.17	2.93	2.53	1.32	0.94		366	2.83	1.62		632	3.04
	0.781	586	6.89	2.76	2.94	0.97	0.69		417	2.77	1.19		721	2.76
	0.468	306	4.58	3.79	1.83	2.50	1.78		218	3.37	3.07		377	4.16
	0.547	374	5.24	3.63	2.04	2.03	1.45		266	3.32	2.50		460	3.87
60°	0.625	445	5.88	3.49	2.31	1.64	1.17	67.7°	317	3.29	2.02	54.6°	547	3.71
	0.703	514	6.54	3.37	2.64	1.28	0.91		366	3.27	1.57		632	3.47
	0.781	586	7.41	3.21	3.10	0.88	0.63		417	3.23	1.08		721	3.24
	0.468	306	4.41	3.84	2.02	2.78	1.98		218	3.54	3.42		377	4.13
	0.547	374	5.19	3.75	2.29	2.36	1.61		266	3.53	2.78		460	4.00
75°	0.625	445	5.92	3.62	2.61	1.83	1.30	79.2°	317	3.43	2.25	71.7°	547	3.78
	0.703	514	6.69	3.52	2.95	1.39	0.99		366	3.40	1.71		632	3,63
	0.781	586	7.55	3.44	3.33				417	3.35			721	3.50

E.C.Thompson, Jr.
A.F. Hubbard

Figure XXVI

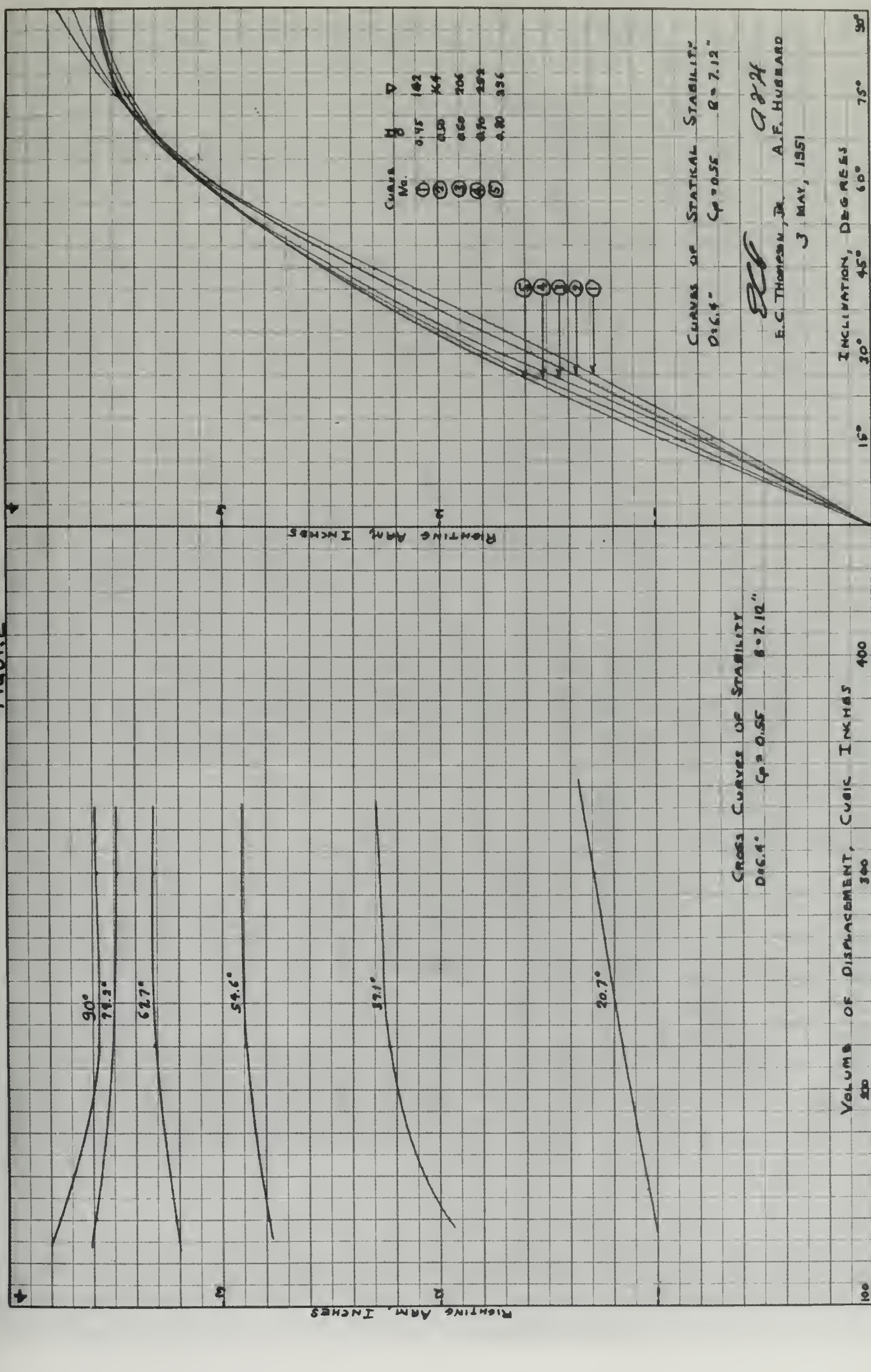
FIGURE XXVI
CROSS CURVES OF STABILITY
Cp = 0.55
B = 7.10"
RIGHTING ARM, INCHES
VOLUME OF DISPLACEMENT, CUBIC INCHES
100
200
300
400
90°
62.7°
54.6°
20.7°
CURVES OF STATICAL STABILITY
Cp = 0.55
B = 7.12"
E.C. THOMPSON, JR.
A.F. HUBBARD
3 MAY, 1951
INCLINATION, DEGREES
15°
30°
45°
60°
75°
90°

Figure XXVII

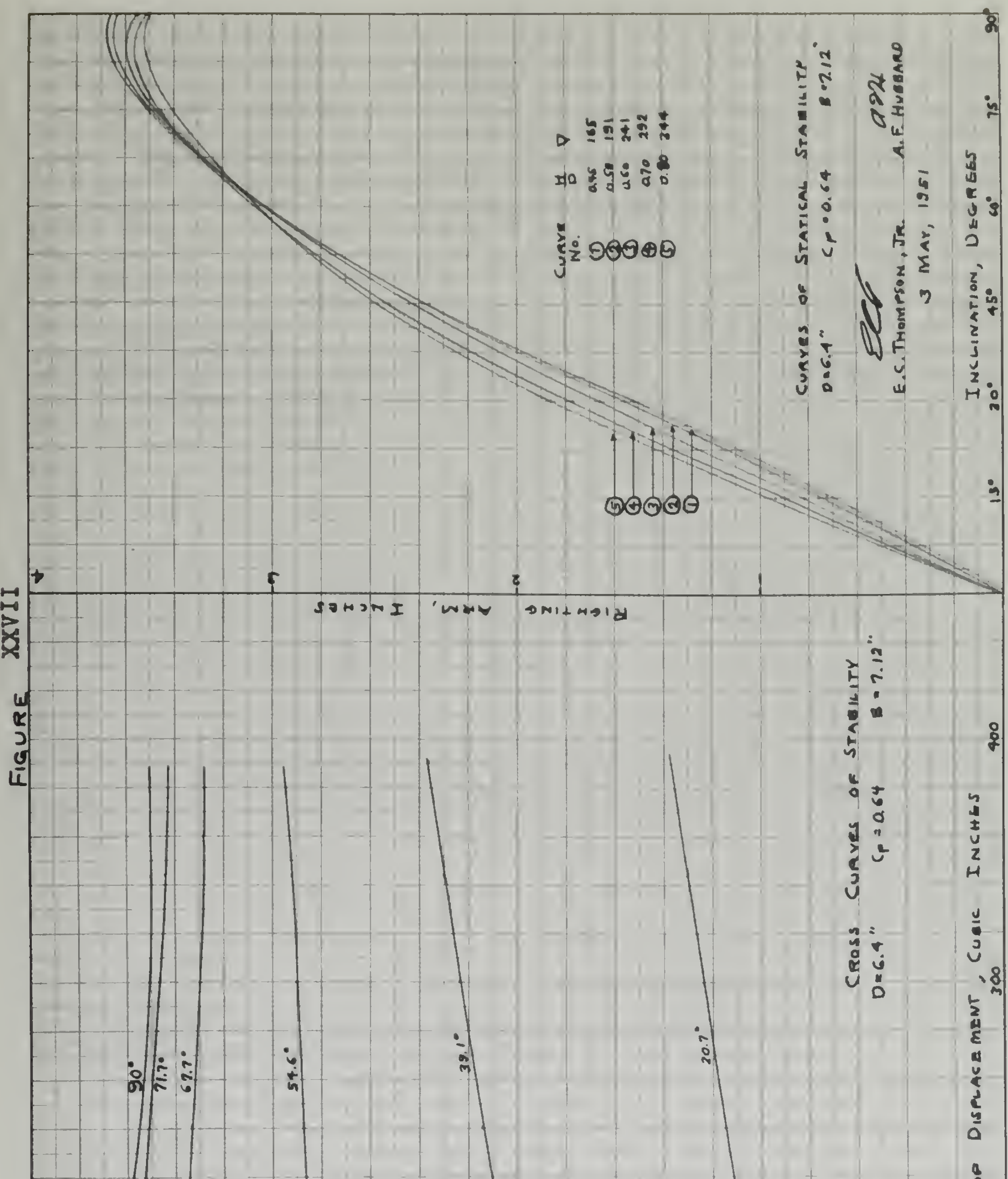

Figure XXVIII

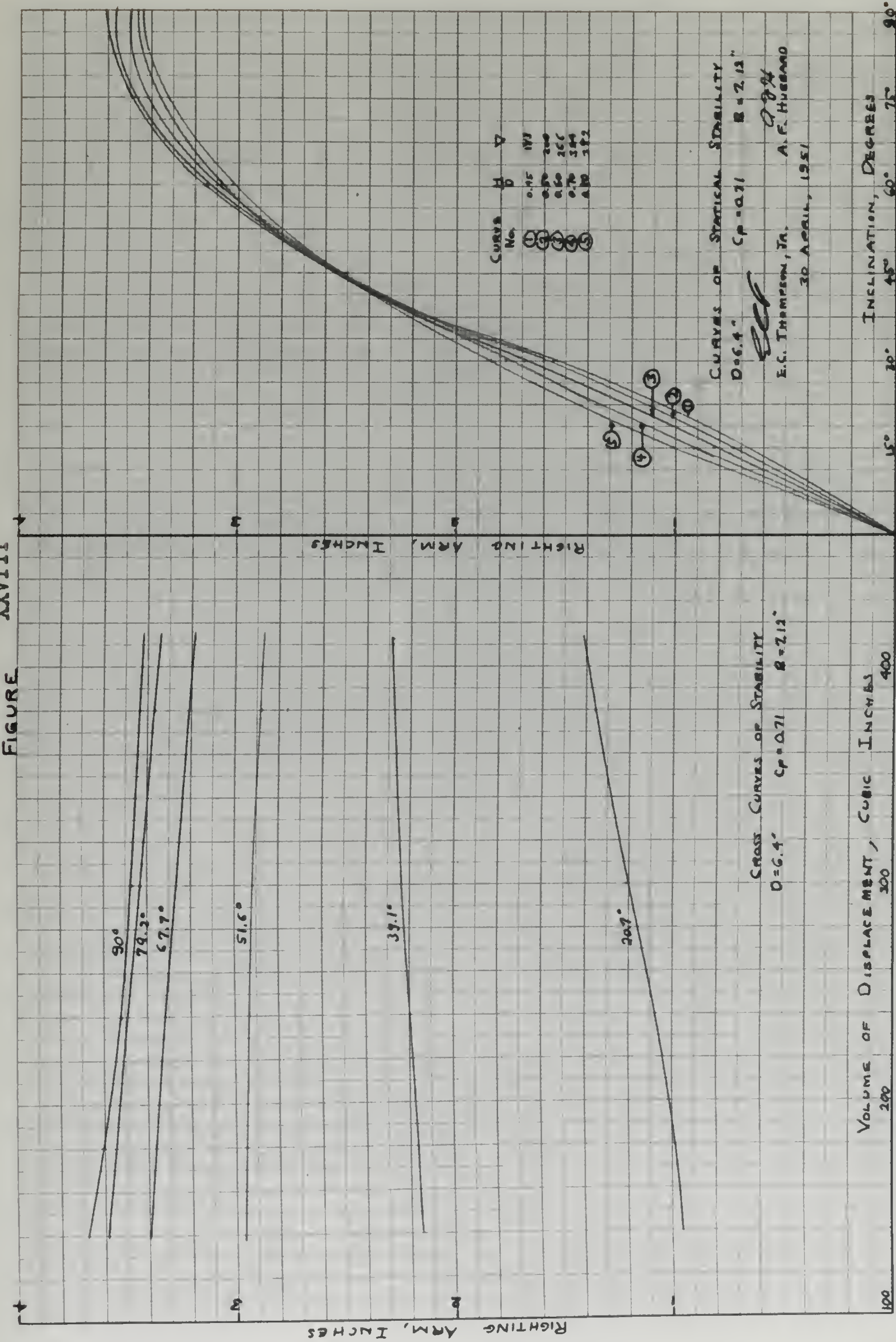

Figure XXIX

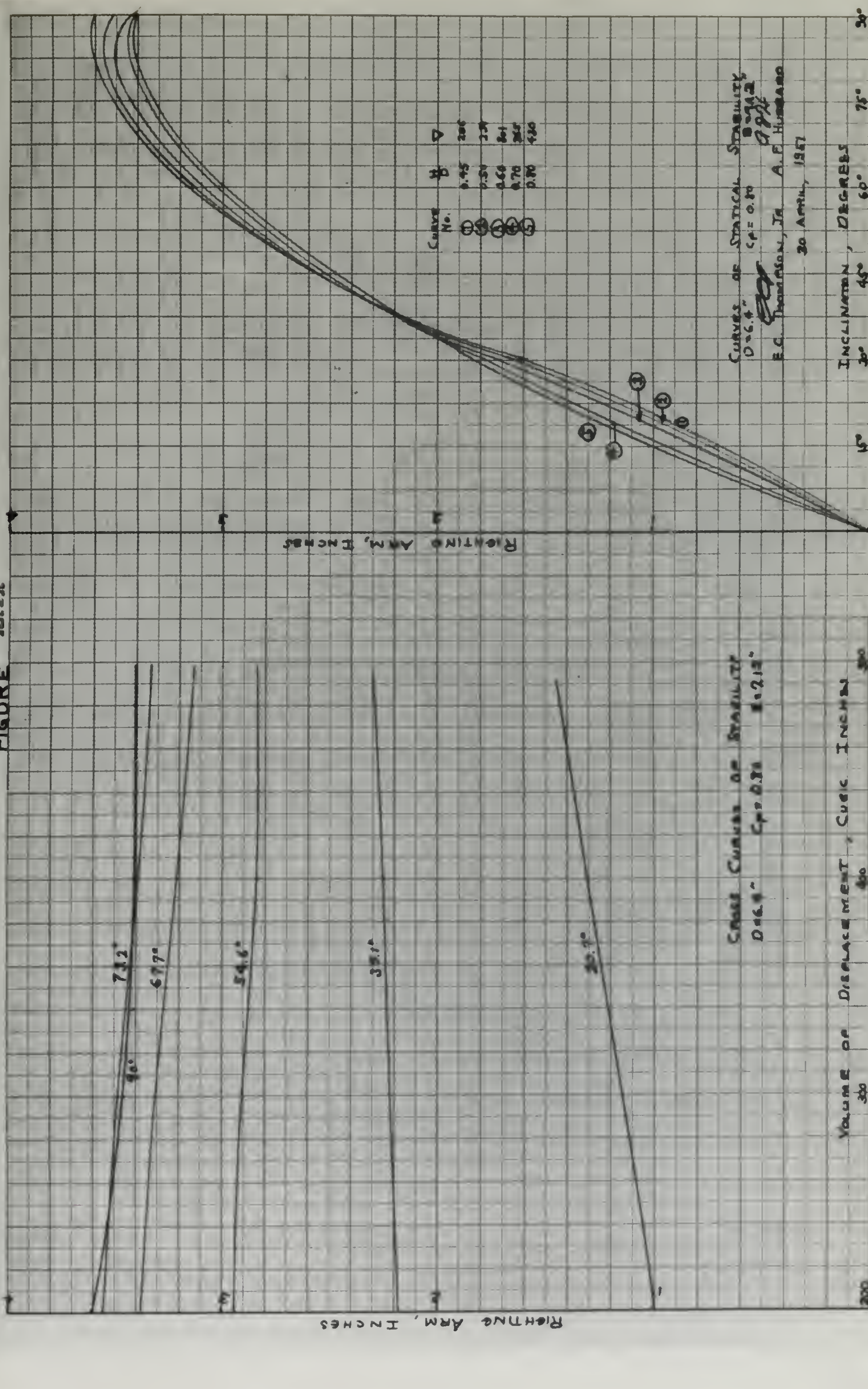
FIGURE XXIX
CROSS CURVES OF STABILITY
VOLUME OF DISPLACEMENT, CUBIC INCHES
RIGHTING ARM, INCHES
CURVES OF STATICAL STABILITY
E.C. THOMPSON, JR   A.F. HUBBARD
30 APRIL, 1957
INCLINATION, DEGREES

Figure XXX

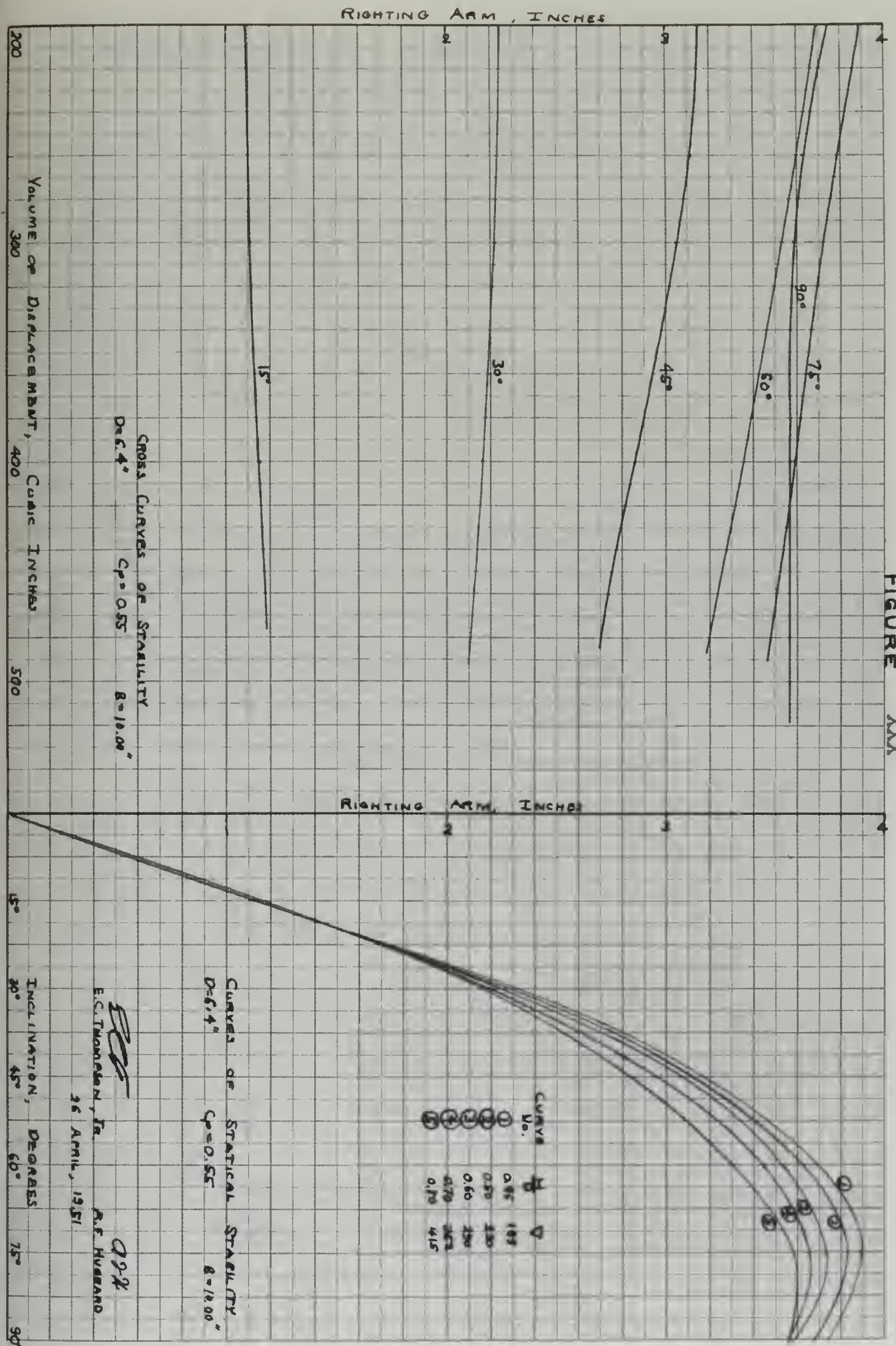
RIGHTING ARM, INCHES
VOLUME OF DISPLACEMENT, CUBIC INCHES
CROSS CURVES OF STABILITY
D=6.4" Cp=0.55 B=10.00"
FIGURE XXX
CURVES OF STATICAL STABILITY
D=6.4" Cp=0.55 B=10.00"
INCLINATION, DEGREES
E.C. THOMPSON, JR.
R.F. HUBBARD
26 APRIL, 1951

Figure XXXI

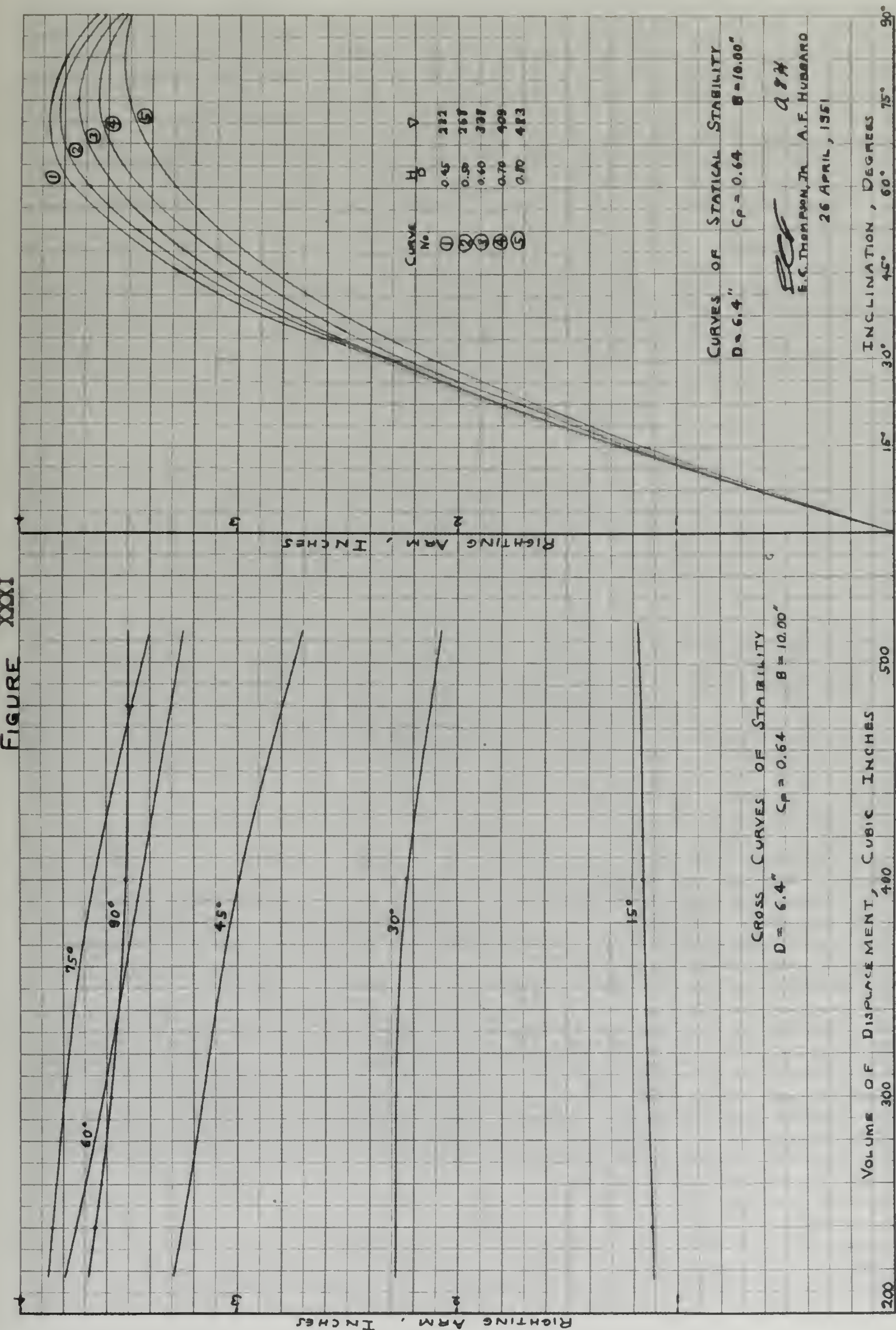
FIGURE XXXI
CURVES OF STATICAL STABILITY
D = 6.4" Cp = 0.64 B = 10.00"
CURVE No. H/B ∇
0.45 232
0.50 268
0.60 328
0.70 409
0.80 483
E.C. THOMPSON, JR. A.F. HUBBARD
26 APRIL, 1951
INCLINATION, DEGREES
RIGHTING ARM, INCHES
CROSS CURVES OF STABILITY
D = 6.4" Cp = 0.64 B = 10.00"
VOLUME OF DISPLACEMENT, CUBIC INCHES

Figure XXXII

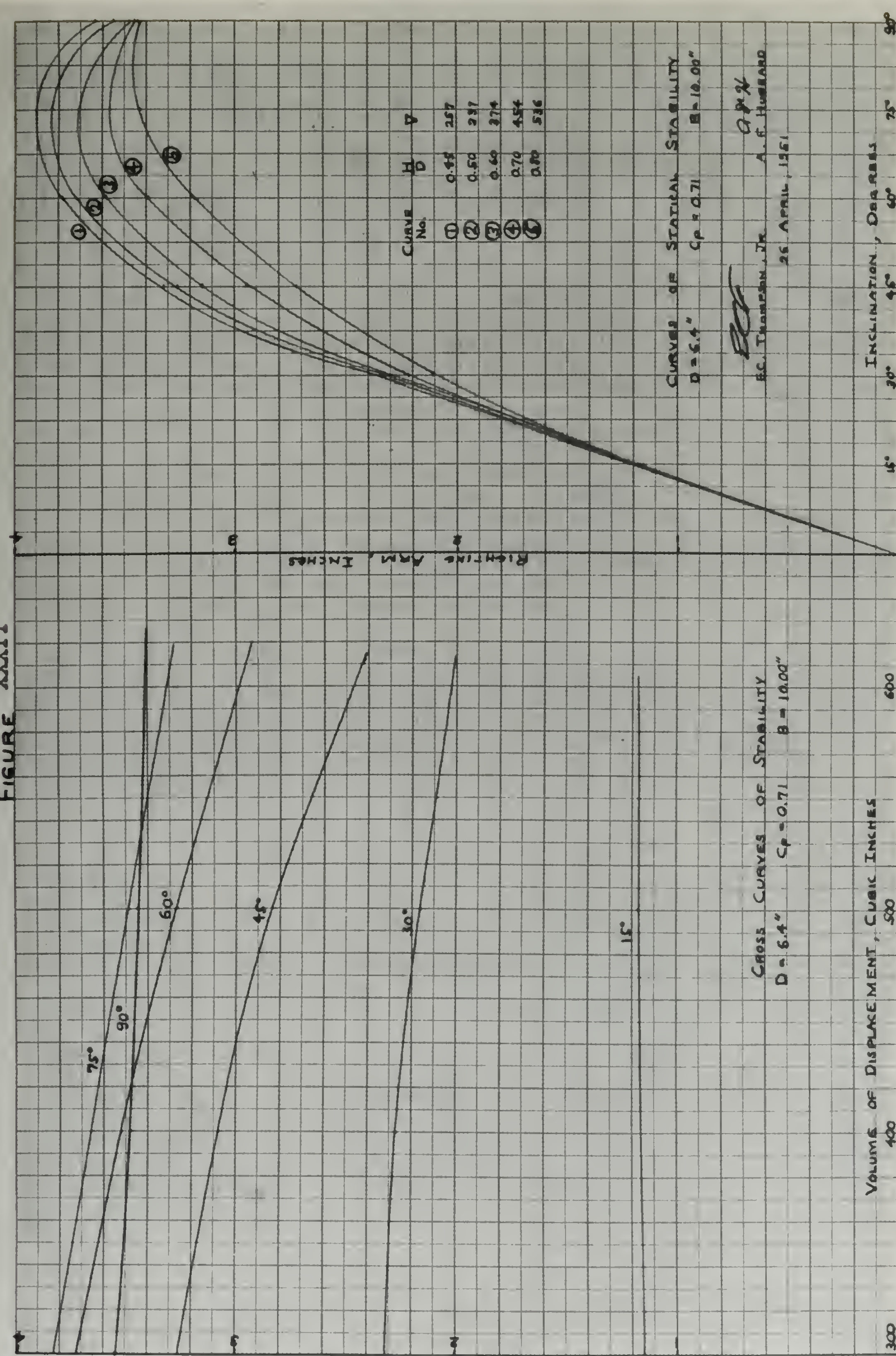

Figure XXXIII

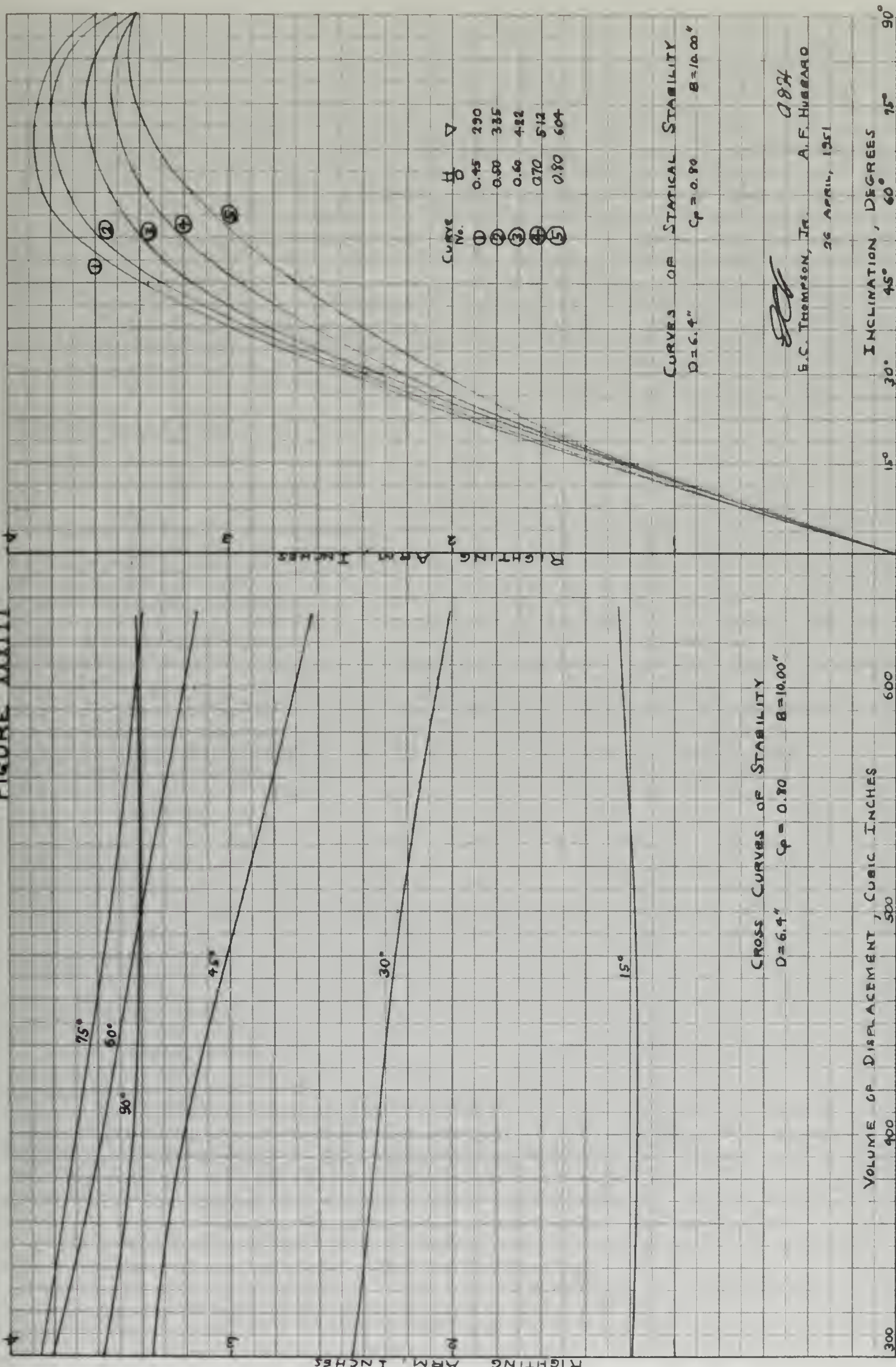

Figure XXXIV

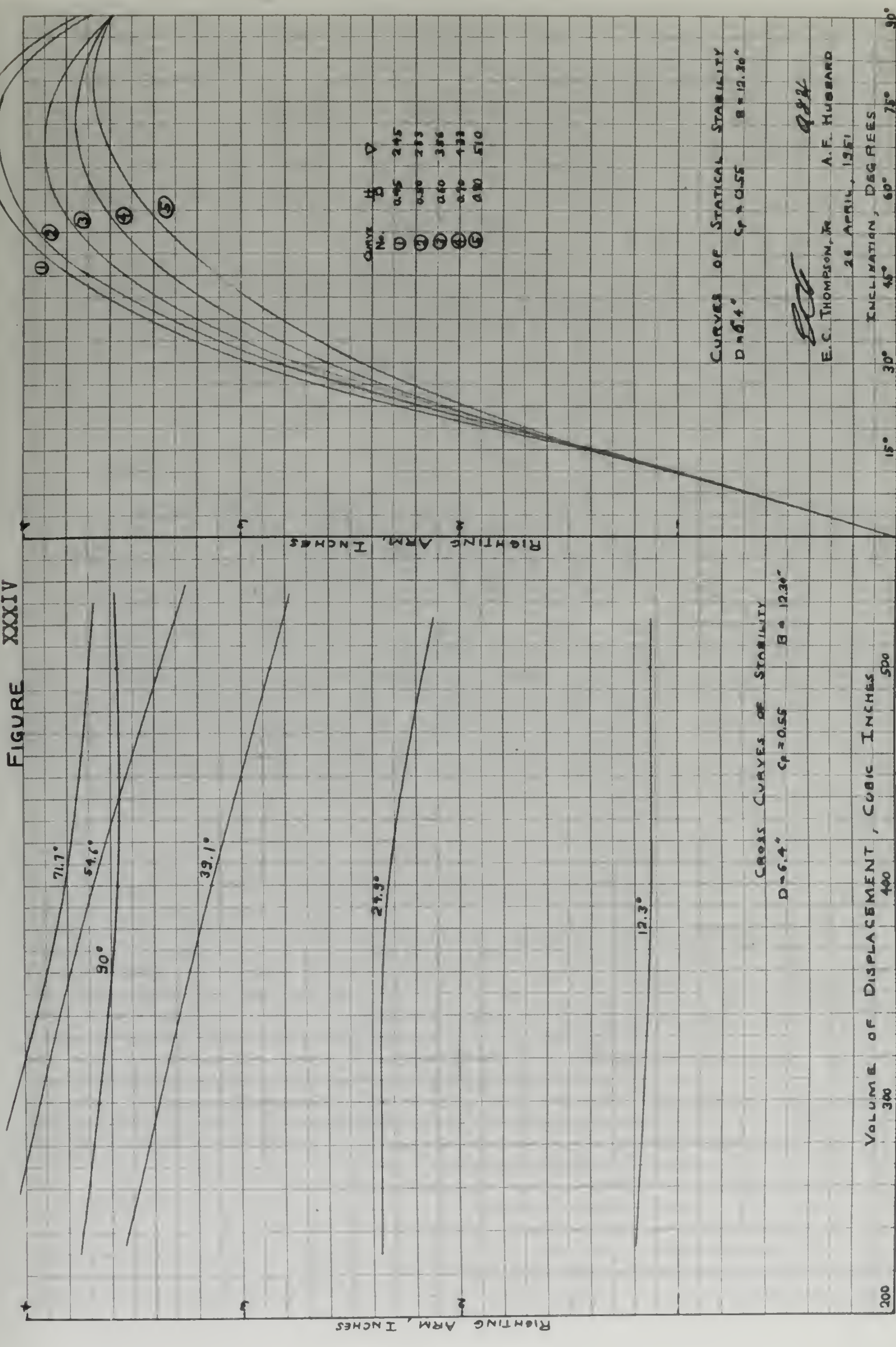

Figure XXXV

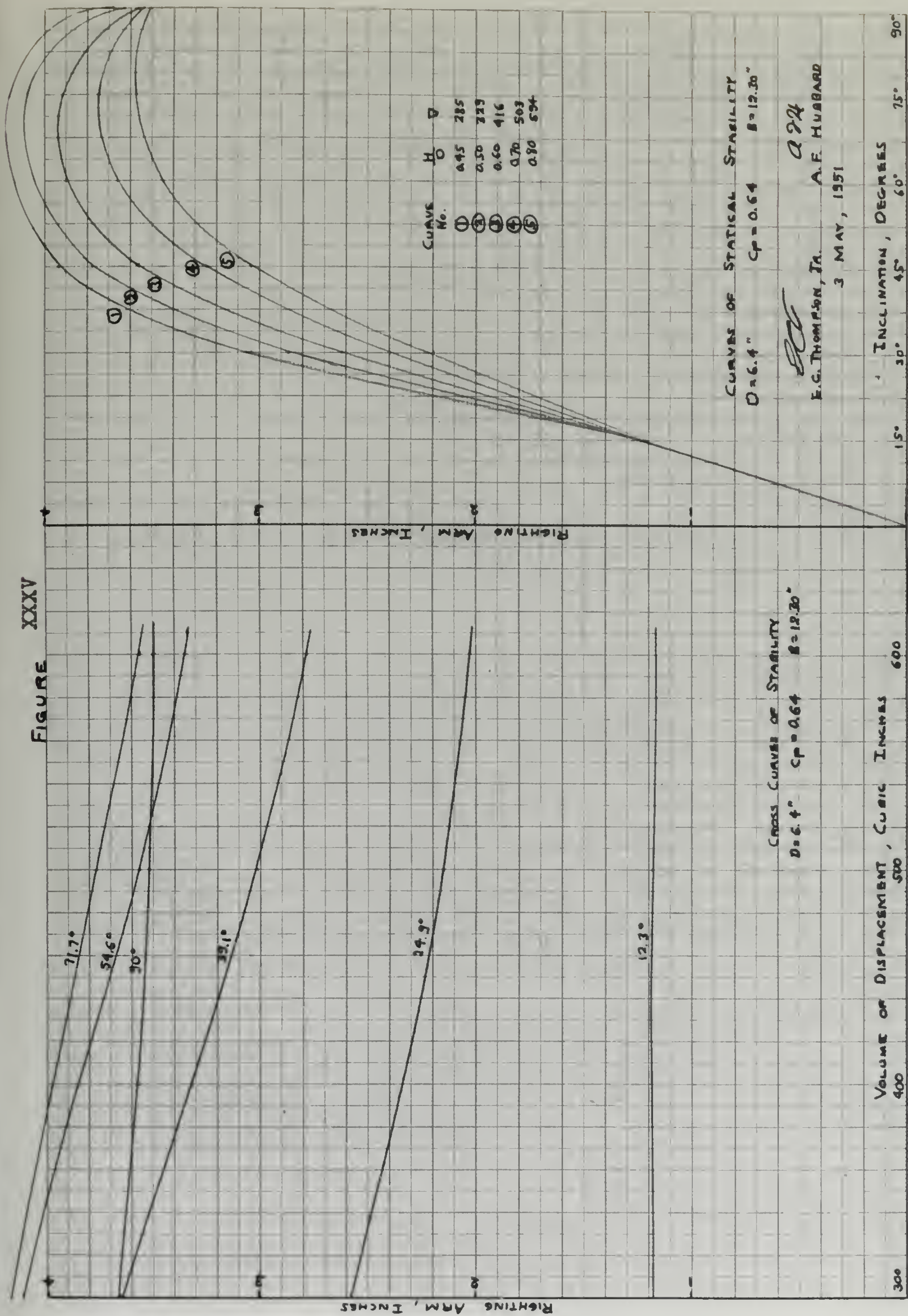
FIGURE XXXV
Curves of Statical Stability
D = 6.4"   Cp = 0.64   B = 12.30"
Curve No.   H/D   ∇
1   0.45   285
2   0.50   329
3   0.60   416
4   0.70   503
5   0.80   594
E.G. Thompson, Jr.   A.F. Hubbard
3 May, 1951
Inclination, Degrees
15°
30°
45°
60°
75°
90°
Righting Arm, Inches
Cross Curves of Stability
D = 6.4"   Cp = 0.64   B = 12.30"
71.7°
54.6°
90°
39.1°
24.9°
12.3°
Volume of Displacement, Cubic Inches
300
400
500
600

Figure XXXVI

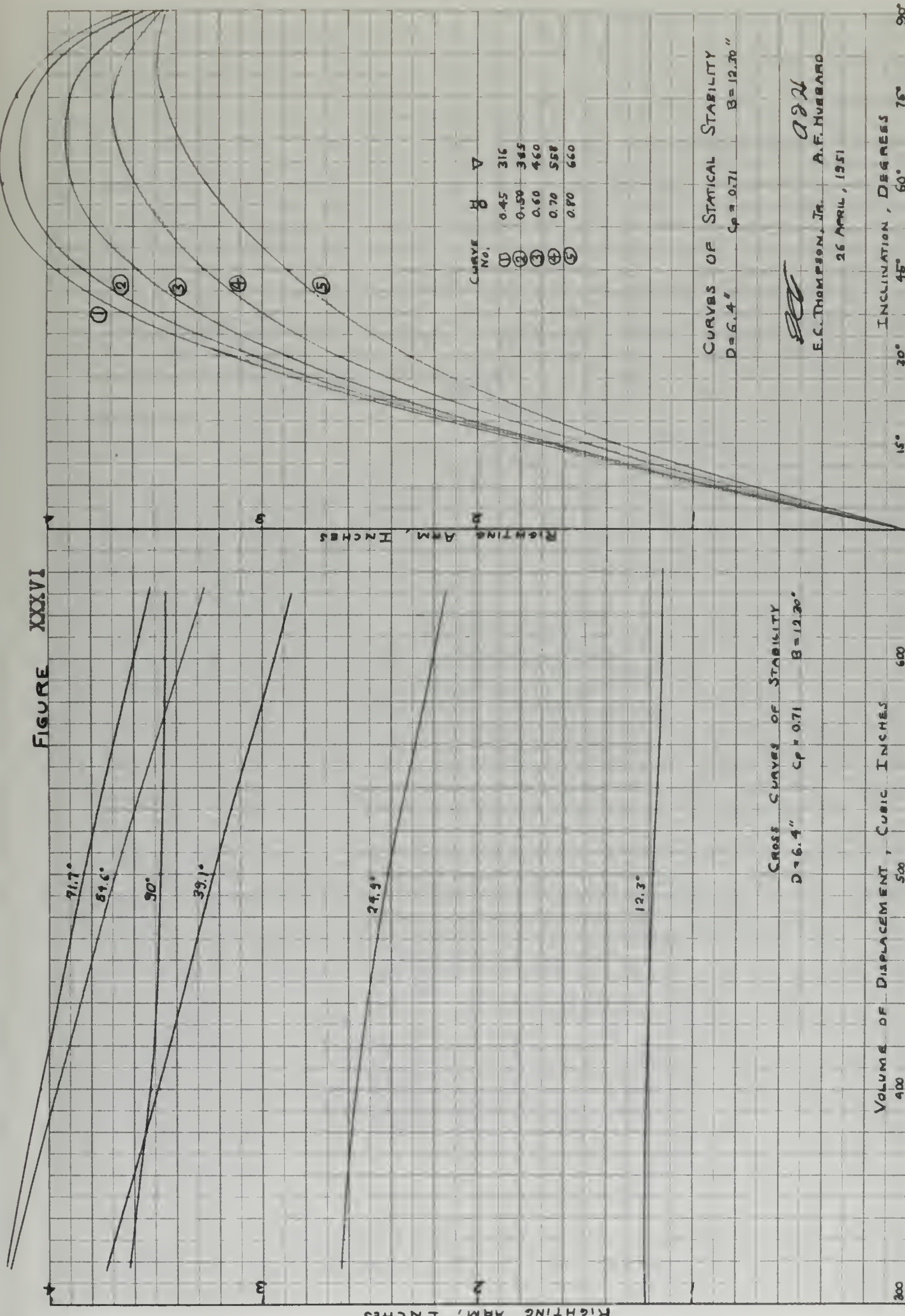

Figure XXXVII

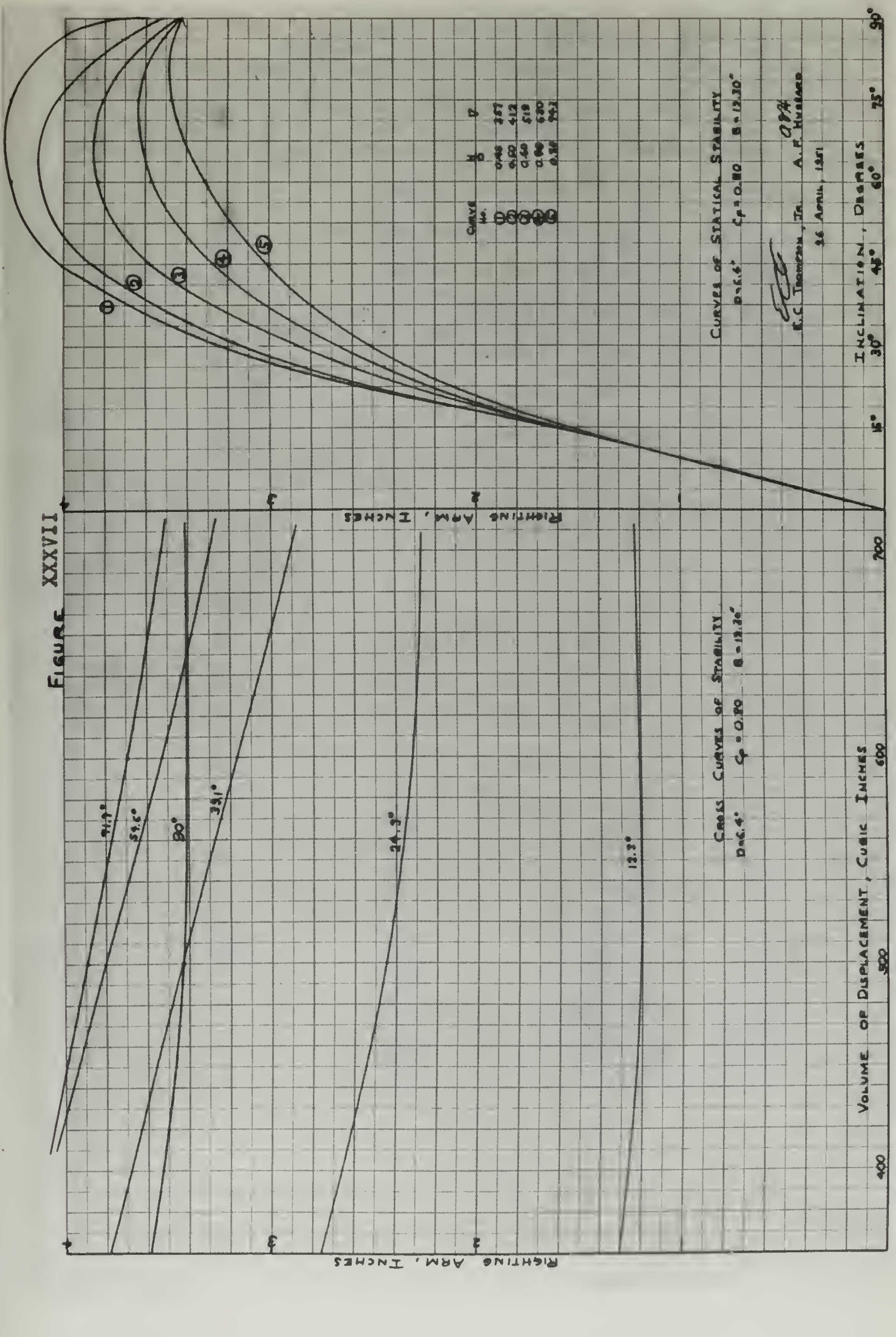

TABLE XIV

VALUES OF KZ AND KZ/B

$D = 6.4''$ $C_p = 0.55$ $B = 7.12''$

H/D	∇	Angle	KZ	KZ/B
0.45	142	15°	0.74	0.104
		30	1.48	0.208
		45	2.31	0.324
		60	3.04	0.427
		75	3.49	0.491
		90	3.77	0.530
0.50	164	15°	0.76	0.107
		30	1.57	0.221
		45	2.39	0.336
		60	3.04	0.427
		75	3.48	0.489
		90	3.67	0.515
0.60	206	15°	0.82	0.115
		30	1.70	0.239
		45	2.50	0.351
		60	3.11	0.437
		75	3.48	0.489
		90	3.58	0.503
0.70	252	15°	0.86	0.121
		30	1.78	0.250
		45	2.52	0.354
		60	3.11	0.437
		75	3.45	0.484
		90	3.57	0.501
0.80	296	15°	0.97	0.136
		30	1.83	0.257
		45	2.54	0.357
		60	3.11	0.437
		75	3.42	0.481
		90	3.56	0.500

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TABLE XV

VALUES OF KZ AND KZ/B

$D = 6.4''$ $C_p = 0.64$ $B = 7.12''$

H/D	∇	Angle	KZ	KZ/B
0.45	165	15°	0.73	0.103
		30	1.52	0.213
		45	2.36	0.332
		60	3.05	0.429
		75	3.50	0.492
		90	3.66	0.514
0.50	191	15°	0.76	0.107
		30	1.56	0.219
		45	2.38	0.334
		60	3.06	0.430
		75	3.48	0.489
		90	3.63	0.510
0.60	241	15°	0.82	0.115
		30	1.66	0.233
		45	2.45	0.344
		60	3.06	0.430
		75	3.46	0.486
		90	3.55	0.498
0.70	292	15°	0.90	0.117
		30	1.76	0.247
		45	2.51	0.353
		60	3.09	0.435
		75	3.44	0.484
		90	3.51	0.493
0.80	344	15°	0.94	0.132
		30	1.85	0.260
		45	2.57	0.361
		60	3.11	0.437
		75	3.43	0.482
		90	3.50	0.492

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TABLE XVI

VALUES OF KZ AND KZ/B

$D = 6.4''$ $C_p = 0.71$ $B = 7.12''$

H/D	∇	Angle	KZ	KZ/B
0.45	183	15°	0.70	0.098
		30	1.55	0.218
		45	2.50	0.351
		60	3.15	0.443
		75	3.49	0.490
		90	3.61	0.507
0.50	204	15°	0.73	0.103
		30	1.59	0.223
		45	2.50	0.351
		60	3.14	0.441
		75	3.48	0.489
		90	3.56	0.500
0.60	266	15°	0.82	0.117
		30	1.69	0.238
		45	2.51	0.352
		60	3.11	0.437
		75	3.42	0.480
		90	3.49	0.490
0.70	324	15°	0.92	0.129
		30	1.77	0.249
		45	2.52	0.354
		60	3.06	0.430
		75	3.36	0.472
		90	3.46	0.486
0.80	382	15°	1.01	0.142
		30	1.85	0.260
		45	2.52	0.354
		60	3.03	0.425
		75	3.32	0.466
		90	3.44	0.483

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TABLE XVII

VALUES OF KZ AND KZ/B

D = 6.4" $\quad$ C_p = 0.80 $\quad$ B = 7.12"

H/D	∇	Angle	KZ	KZ/B
0.45	206	15°	0.70	0.098
		30	1.59	0.223
		45	2.48	0.348
		60	3.16	0.444
		75	3.51	0.493
		90	3.60	0.505
0.50	239	15°	0.74	0.104
		30	1.63	0.229
		45	2.51	0.352
		60	3.14	0.441
		75	3.48	0.488
		90	3.51	0.492
0.60	301	15°	0.82	0.105
		30	1.71	0.240
		45	2.50	0.351
		60	3.10	0.435
		75	3.43	0.482
		90	3.42	0.480
0.70	365	15°	0.92	0.129
		30	1.79	0.251
		45	2.49	0.350
		60	3.02	0.423
		75	3.36	0.471
		90	3.41	0.478
0.80	430	15°	1.01	0.142
		30	1.84	0.258
		45	2.48	0.348
		60	3.01	0.422
		75	3.32	0.466
		90	3.41	0.478

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TABLE XVIII

VALUES OF KZ AND KZ/B

$D = 6.4"$ $C_p = 0.55$ $B = 10.00"$

H/D	∇	Angle	KZ	KZ/B
0.45	199	15°	1.09	0.109
		30	2.24	0.224
		45	3.16	0.316
		60	3.69	0.369
		75	3.89	0.389
		90	3.74	0.374
0.50	230	15°	1.10	0.110
		30	2.22	0.222
		45	3.14	0.314
		60	3.64	0.364
		75	3.83	0.383
		90	3.68	0.368
0.60	290	15°	1.11	0.111
		30	2.22	0.222
		45	3.07	0.307
		60	3.54	0.354
		75	3.73	0.373
		90	3.60	0.360
0.70	352	15°	1.12	0.112
		30	2.21	0.221
		45	2.97	0.297
		60	3.44	0.344
		75	3.65	0.365
		90	3.57	0.357
0.80	415	15°	1.15	0.115
		30	2.13	0.213
		45	2.83	0.283
		60	3.31	0.331
		75	3.58	0.358
		90	3.57	0.357

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TABLE XIX

VALUES OF KZ AND KZ/B

$D = 6.4''$ $C_p = 0.64$ $B = 10.00''$

H/D	∇	Angle	KZ	KZ/B
0.45	232	15°	1.12	0.112
		30	2.29	0.229
		45	3.26	0.326
		60	3.76	0.376
		75	3.84	0.385
		90	3.66	0.366
0.50	268	15°	1.12	0.112
		30	2.28	0.228
		45	3.22	0.322
		60	3.67	0.367
		75	3.82	0.382
		90	3.62	0.362
0.60	338	15°	1.13	0.113
		30	2.26	0.226
		45	3.09	0.309
		60	3.55	0.355
		75	3.75	0.375
		90	3.54	0.354
0.70	409	15°	1.15	0.115
		30	2.22	0.222
		45	2.97	0.297
		60	3.43	0.343
		75	3.64	0.364
		90	3.52	0.352
0.80	483	15°	1.17	0.117
		30	2.12	0.212
		45	2.78	0.278
		60	3.28	0.328
		75	3.50	0.350
		90	3.50	0.350

TABLE XX

VALUES OF KZ AND KZ/b

D = 6.4"　　C_p = 0.71　　B = 10.00"

H/D	∇	Angle	KZ	KZ/B
0.45	257	15°	1.15	0.115
		30	2.34	0.234
		45	3.32	0.332
		60	3.78	0.378
		75	3.89	0.389
		90	3.63	0.363
0.50	297	15°	1.15	0.115
		30	2.32	0.232
		45	3.26	0.326
		60	3.72	0.372
		75	3.83	0.383
		90	3.55	0.355
0.60	374	15°	1.15	0.115
		30	2.29	0.229
		45	3.14	0.314
		60	3.58	0.358
		75	3.71	0.371
		90	3.49	0.349
0.70	454	15°	1.16	0.116
		30	2.22	0.222
		45	2.95	0.295
		60	3.39	0.339
		75	3.57	0.357
		90	3.46	0.346
0.80	536	15°	1.17	0.117
		30	2.11	0.211
		45	2.72	0.272
		60	3.18	0.318
		75	3.43	0.343
		90	3.44	0.344

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TABLE XXI

VALUES OF KZ AND KZ/B

D = 6.4" C_p = 0.80 B = 10.00"

H/D	∇	Angle	KZ	KZ/B
0.45	290	15°	1.19	0.119
		30	2.47	0.247
		45	3.36	0.336
		60	3.84	0.384
		75	3.87	0.387
		90	3.60	0.360
0.50	335	15°	1.18	0.118
		30	2.39	0.239
		45	3.31	0.331
		60	3.72	0.372
		75	3.81	0.381
		90	3.51	0.351
0.60	422	15°	1.16	0.116
		30	3.32	0.232
		45	3.16	0.316
		60	3.53	0.353
		75	3.66	0.366
		90	3.42	0.342
0.70	512	15°	1.19	0.119
		30	2.23	0.223
		45	2.93	0.293
		60	3.37	0.337
		75	3.52	0.352
		90	3.41	0.341
0.80	604	15°	1.24	0.124
		30	2.06	0.206
		45	2.71	0.271
		60	3.17	0.317
		75	3.43	0.343
		90	2.41	0.341

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TABLE XXII

VALUES OF KZ AND KZ/B

$D = 6.4''$ $\qquad C_p = 0.55$ $\qquad B = 12.30''$

H/D	∇	Angle	KZ	KZ/B
0.45	245	15°	1.42	0.115
		30	2.95	0.240
		45	3.77	0.307
		60	4.13	0.336
		75	4.19	0.341
		90	3.74	0.305
0.50	283	15°	1.42	0.115
		30	2.84	0.231
		45	3.70	0.301
		60	4.06	0.330
		75	4.09	0.332
		90	3.68	0.299
0.60	356	15°	1.41	0.115
		30	2.73	0.222
		45	3.52	0.286
		60	3.87	0.315
		75	3.87	0.315
		90	3.59	0.292
0.70	433	15°	1.40	0.114
		30	2.61	0.212
		45	3.28	0.267
		60	3.67	0.298
		75	3.75	0.305
		90	3.57	0.290
0.80	510	15°	1.37	0.111
		30	2.25	0.215
		45	3.07	0.249
		60	3.50	0.285
		75	3.70	0.301
		90	3.57	0.290

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TABLE XXIII

VALUES OF KZ AND KZ/B

D = 6.4" C_p = 0.64 B = 12.30"

H/D	∇	Angle	KZ	KZ/B
0.45	285	15°	1.24	0.101
		30	3.05	0.248
		45	3.93	0.320
		60	4.13	0.336
		75	4.11	0.334
		90	3.68	0.299
0.50	329	15°	1.24	0.101
		30	2.87	0.233
		45	3.78	0.307
		60	4.02	0.327
		75	4.05	0.229
		90	3.62	0.295
0.60	416	15°	1.22	0.099
		30	2.63	0.214
		45	3.56	0.290
		60	3.90	0.317
		75	3.92	0.319
		90	3.56	0.289
0.70	502	15°	1.22	0.099
		30	2.40	0.195
		45	3.26	0.265
		60	3.66	0.298
		75	3.75	0.307
		90	3.54	0.288
0.80	594	15°	1.11	0.090
		30	2.20	0.179
		45	3.04	0.247
		60	3.45	0.281
		75	3.57	0.291
		90	3.49	0.284

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TABLE XXIV

VALUES OF KZ AND KZ/B

$D = 6.4"$ $C_p = 0.71$ $B = 12.30"$

H/D	∇	Angle	KZ	KZ/B
0.45	316	15°	1.36	0.111
		30	3.13	0.254
		45	3.94	0.320
		60	5.00	0.406
		75	4.15	0.337
		90	3.63	0.295
0.50	365	15°	1.45	0.118
		30	3.05	0.248
		45	3.83	0.311
		60	4.11	0.334
		75	4.08	0.332
		90	3.56	0.289
0.60	460	15°	1.47	0.120
		30	2.88	0.234
		45	3.58	0.291
		60	3.87	0.315
		75	3.90	0.317
		90	3.49	0.284
0.70	558	15°	1.52	0.124
		30	2.65	0.216
		45	3.28	0.267
		60	3.60	0.293
		75	3.50	0.285
		90	3.46	0.281
0.80	660	15°	1.52	0.124
		30	2.31	0.188
		45	2.87	0.233
		60	3.26	0.265
		75	3.47	0.281
		90	3.44	0.280

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VALUES OF KZ AND KZ/B

D = 6.4" C_p = 0.80 B = 12.30"

H/D	∇	Angle	KZ	KZ/B
0.45	357	15°	1.62	0.132
		30	3.25	0.264
		45	4.01	0.326
		60	4.26	0.346
		75	4.17	0.339
		90	3.59	0.292
0.50	412	15°	1.55	0.126
		30	3.14	0.255
		45	3.86	0.313
		60	4.12	0.335
		75	4.02	0.327
		90	3.52	0.286
0.60	519	15°	1.50	0.122
		30	2.87	0.233
		45	3.58	0.291
		60	3.83	0.311
		75	3.81	0.310
		90	3.42	0.278
0.70	630	15°	1.50	0.122
		30	2.65	0.215
		45	3.27	0.266
		60	3.57	0.290
		75	3.64	0.296
		90	3.42	0.278
0.80	743	15°	1.48	0.120
		30	2.51	0.204
		45	3.00	0.244
		60	3.31	0.269
		75	3.48	0.283
		90	3.41	0.277

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